HBCDD concentrations in EPS/XPS products and waste streams

Inventory in the Netherlands

Final

Ministry of Infrastructure and Water Management
March 2018

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SUMMARY

In 2013 hexabromocyclododecane (HBCDD), a flame retardant that was widely used in EPS and XPS foams between 1970 and 2015, was added to the Stockholm Convention on Persistent Organic Pollutants (POPs). As a result, both production and use of HBCDD-containing products are prohibited for all Parties to the Convention, including the Netherlands.

In 2016 the Dutch Ministry of Infrastructure and Water Management (previously Ministry of Infrastructure and Environment) took stock of the volumes of various product and waste streams possibly containing HBCDD in the Netherlands [1]. In 2017, this investigation is followed up by an investigation on the HBCDD concentrations in the various product and waste streams. This document presents the results of that investigation.

The investigation of the HBCDD content in EPS and XPS products and waste streams was carried out in three consecutive phases:

- Phase 1 – 1,150 measurements of bromine with X-ray fluorescence spectroscopy (XRF) for initial screening of a large number of samples for brominated compounds;
- Phase 2 – 69 measurements of the solubility of the brominated compound in the samples that were found to contain bromine in the first phase followed by XRF;
- Phase 3 – 28 measurements of HBCDD content with Liquid Chromatography – Mass Spectroscopy (LC-MS) in the samples that showed to contain a soluble brominated compound in phase 2.

In general the investigation revealed that:

1. All new EPS/XPS products on the Dutch market contain less than 100 ppm HBCDD;
2. All EPS/XPS waste streams that are recycled in the Netherlands contain less than 1000 ppm HBCDD;
3. Not all EPS/XPS waste streams with HBCDD content exceeding 1000 ppm can be separated from other waste streams to be made available for incineration or the PolyStyreneLoop project.

In more detail the investigation has led to the following conclusions:

Measurement techniques

- XRF screening detects brominated flame retardants effectively;
- XRF with extraction distinguishes between PolyFR and other flame retardants;
- Cost and lead time of LC-MS measurement of HBCDD in EPS/XPS restrict its usefulness for everyday operations.

Regarding HBCDD in EPS iceboxes and horticulture products

- EPS from ice boxes and horticulture products does not contain HBCDD.

Regarding HBCDD in EPS packaging material

- New packaging materials do not contain HBCDD;
- Packaging EPS collected from household waste recycling centres (HWRCs) is contaminated with construction EPS and XPS;
- A small part of packaging EPS on HWRCs contains HBCDD.

Regarding HBCDD in construction material

- Some newly domestically produced EPS products contain other flame retardants (FR-720 of SR-130) with similar acetone-solubility to HBCDD;
- Construction material collected from demolition sites generally contains HBCDD in concentrations above 1000 ppm;
- The light-fine fraction from sorting installation (an intermediate product) may contain HBCDD concentrations above 100 ppm.

Regarding HBCDD in transportation sector

- The occurrence of HBCDD in the transportation sector is very low.

Regarding HBCDD in EPS recyclates

- Loose particles may contain HBCDD concentrations above 100 ppm;
- Polystyrene granulate from ice boxes does not contain HBCDD.

In view of the results of this investigation we make the following recommendations to the Ministry of Infrastructure and Water Management:

1. Inform EPS packaging waste recyclers of the legal requirement that only products and materials containing less than 100 ppm HBCDD are permitted on the market;
2. Inform the management of HWRCs on the importance of separating packaging EPS from construction EPS;
3. Repeat HBCDD measurement on EPS packaging collected from HWRCs;
4. Request that producers and importers of packaging EPS reduce the use of flame retardants in their EPS packaging.

1 INTRODUCTION

1.1 General

Brominated flame retardants are widely used in expanded polystyrene (EPS) and extruded polystyrene (XPS) products to reduce their flammability, if this is required by regulations. All EPS and XPS used in the construction sector in the Netherlands between 1975 and 2015 contain the brominated flame retardant hexabromocyclododecane (HBCDD) [1, 7].

In 2013, HBCDD was added to the Stockholm Convention on Persistent Organic Pollutants (POPs). As a result, both production and use of HBCDD-containing products are prohibited for all Parties to the Convention, including the Netherlands. The phasing-out of such products in the European Union was initially regulated through the regulation REACH ((EC) 1907/2006).

The Stockholm Convention obligates the Netherlands government to develop and execute a national implementation plan that must lead to environmentally sound management of HBCDD. The first step in developing such a plan is to make an inventory of HBCDD and materials containing this flame retardant in the Netherlands. In 2016, the Dutch Ministry of Infrastructure and Environment took stock of the volumes of various product and waste streams possibly containing HBCDD in the Netherlands [1]. At that time, the concentrations of HBCDD in those streams were not determined.

In 2017, the Ministry of Infrastructure and Water Management (formerly Ministry of Infrastructure and Environment) decided to investigate HBCDD concentrations in the various product and waste streams. This document presents the results of that investigation. This project is based on the plan 'Inventory of concentrations of HBCDD in a number of waste streams' (see Annex 1).

To supervise the study a Steering Committee was formed (see Annex 2).

1.2 Objective

The main research objective is to determine the actual concentration of HBCDD in various product and waste streams identified in the report 'HBCDD in EPS/XPS waste in the Netherlands — inventory of size and value'. In this respect the report has to answer three central questions for correct use, recycling and disposal are:

1. Do all EPS/XPS products on the Dutch market contain less than 100 ppm HBCDD?
2. Do all EPS/XPS waste streams that are recycled contain less than 1000 ppm HBCDD?
3. Can all EPS/XPS waste streams with HBCDD content exceeding 1000 ppm be separated from other waste streams and are they available for incineration or the PolyStyreneLoop project?

1.3 Assessment framework

In the European Union, the framework for assessing HBCDD concentrations is defined by REACH 1907/2006/EC and POP regulation 850/2004/EC [1]. In the Netherlands, the framework for assessing HBCDD concentrations in waste streams is the policy on EPS recovery and recycling as established in the Dutch National Waste Management Plan 2017 2029 (Landelijk AfvalbeheerPlan 3, LAP3) [5], which entered into force on 28 December 2017. Translations of that document can be found on the EU website [5]. LAP3 includes a special section on EPS (Sectorplan 85 – EPS), which is only available in Dutch and only applies to EPS waste. Although that regulation refers to XPS waste as 'similar to EPS waste', it does not automatically apply to XPS waste.

A translated summary of the Dutch policy on HBCDD concentrations is presented in Table 1.1 (below).

Table 1.1: Summary of Dutch policy on EPS waste [5]

Waste stream	Minimum treatment standard
Packaging EPS	**Recycling**: When recycling packaging EPS, the recyclate (i.e. material produced) must contain no more than 100 ppm HBCDD, as defined in Annex 1 of the POP regulation (850/2004/EC). Whenever packaging EPS cannot be recycled, for example because it is too contaminated, the material must be treated according to the minimum standard for "other recovery"; for example, "Incineration as a form of recovery".
Construction EPS	**"Other recovery" as defined in the POP regulation (850/2004/EC), Art. 7.2 and Annex V, part 1:** Construction EPS can only be treated with a higher quality of recovery if it is kept separate from other material and it can be proven that the construction EPS does not contain HBCDD.

Note that 'construction EPS' coming from demolition projects generally contains HBCDD and therefore cannot be recycled directly into new products. From 1975 to 2015, HBCDD was added as a flame retardant to construction EPS in concentrations of 5,000-10,000 ppm [1]. In EPS produced in 2016 and later, alternative flame retardants[1] have been used to which restrictions such as those on HBCDD do not apply. The stipulations on higher quality of recovery do not apply to such HBCDD-free construction EPS.

1.4 Flame retardants in EPS and XPS products and waste streams

This subsection describes the use of HBCDD in EPS and XPS products and waste streams in the Netherlands.

[1] From 2016 onwards a large part of construction EPS contains the high-molecular-weight flame retardant PolyFR, a polymeric component, though two alternative flame retardants, being the low-molecular-weight FR-720 and SR-130, may also be present.

Occurrence of flame retardant in EPS/XPS

In general, in the Netherlands EPS is used in the applications shown in the photos below.

No.	Description	Appearance
1	packaging	
2	horticulture	
3	ice boxes	
4	construction	
5	civil engineering	
6	transport sector	

The two main categories of EPS applications are ‘packaging’ and ‘construction’. Dutch regulations stipulate that construction EPS should have a certain resistance to thermal attack (i.e. fire). Therefore, EPS waste from demolition sites generally contains a flame retardant. In contrast, a flame retardant is generally not required in packaging EPS, so most EPS packaging waste is retardant-free. In other countries, however, investigations have shown that flame retardants do sometimes occur in EPS packaging waste [7, 11].

Although ‘horticulture’ and ‘ice boxes’ arguably fall into the category of packaging, these are referred to separately because the relevant branches have their own separate EPS waste collection systems [1]. Normally, horticultural and fishing industry EPS should not contain flame retardant, though data on measurements of these categories of material have not been found in the literature.

Similarly, EPS used in civil engineering applications is arguably construction EPS. Nevertheless, this application is referred to separately because construction EPS has to contain a flame retardant for safety reasons, whereas this is not always the case for civil engineering applications [1, 8].

A separate category is EPS used in the transport sector. The relevant literature shows that a flame retardant is used in this category of material [1].

Almost all XPS on the Dutch market is used for construction purposes and therefore contains a flame retardant.

Concentrations

The typical concentration range for the application of HBCDD as a flame retardant in EPS was between 0.5% and 1.0% (5,000-10,000 ppm), with an average of 0.7%. For XPS it was between 0.8% and 2.5% (8,000-25,000 ppm) [1], with an average of 1.5%. HBCDD concentrations are always based on weight not volume.

Shortly before and during 2015, EPS and XPS producers gradually stopped using HBCDD. It is assumed that all new EPS/XPS products used in the Netherlands have been HBCDD-free since August 2016, ICL-IP’s production plant completely stopped producing HBCDD in April 2016 [9].

In EPS and XPS products, HBCDD has been replaced by alternative flame retardants for which the restrictions of the Stockholm Convention and REACH do not apply. A study by the U.S. Environmental Protection Agency (EPA) with input from stakeholders in business, government, academia and environmental organisations concluded that only three chemical compounds are viable alternatives to HBCDD in EPS and XPS [6]. These are the high molecular weight PolyFR, a butadiene styrene brominated copolymer that has been on the market since 2011, and two low-molecular-weight brominated flame retardants:

- FR-720 (Tetrabromobisphenol-A, bis (2,3-dibromopropyl ether))
- SR-130 (Benzene, 1, 1’-(1-methylethylidene)bis[3,5-dibromo-4-(2, 3-dibromo-2-methylpropoxy)])

1.5 Limitations of this inventory

Concentrations only

In line with the project plan (see Annex 1) the scope of this inventory is limited to investigating HBCDD concentrations in EPS and XPS products and waste streams in the Netherlands. Other characteristics of HBCDD in EPS and XPS have not been studied.

Focus on EPS and XPS

HBCDD is used in a wide variety of products. In the European Union, most HBCDD (>95%) is used in EPS and XPS, though it is also used to a far lesser extent in high-impact polystyrene (HIPS) and for polymer dispersion in textiles [1]. The Dutch Ministry of Infrastructure and Water Management has decided to focus this inventory on production, use and disposal of HBCDD-containing EPS and XPS.

Focus on threshold concentrations of 100 ppm and 1000 ppm HBCDD

In this study, the following concentrations are relevant:

- 1000 ppm HBCDD:
  The threshold concentration for waste materials (POP Regulation, Annex IV);
- 100 ppm HBCDD:
  The threshold concentration for newly produced substances, mixtures, materials or products, including recyclates that are marketed (POP Regulation, Annex I).

Terminology

In order to present a simplified overview, this study refers to the products made from expanded polystyrene (EPS) or extruded polystyrene (XPS) using only a few generic terms, such as ‘construction EPS/XPS’, ‘packaging EPS’, ‘horticulture’, ‘ice boxes’ and ‘civil engineering applications’. These terms represent groups of products on the market that have many different purposes, characteristics and trade names.

1.6 Document structure

Section 2 describes the background to this project, including the analysis techniques used to generate the results. The employed measurement programme is described in Section 3 and the measurement results are presented in Section 4. Finally, Section 5 draws conclusions and makes recommendations.

2 BACKGROUND

2.1 Quantities

In 2016, an inventory was made of quantities of EPS and XPS products and waste streams in the Netherlands [1]. The study differentiated between the packaging and construction streams and the estimated collection, recycling and disposal mass flows of EPS packaging waste (Figure 2.1) and EPS/XPS construction waste (Figure 2.2). The Netherlands generates 12.7 kilotons/year of EPS packaging waste. Of this stream, 5.4 kilotons/year are recycled – i.e. 4.4 kilotons/year from fisheries (iceboxes) and horticulture and 1.0 kilotons/year from packaging – and 7.3 kilotons/year are incinerated. The Netherlands also generates 1.15 kilotons/year of construction EPS/XPS waste. Of this stream, 0.1 kilotons/year are recycled, 1 kilotons/year are incinerated and 0.05 kilotons/year go to landfill.

Figure 2.1: Yearly mass flow of packaging EPS waste (2016)

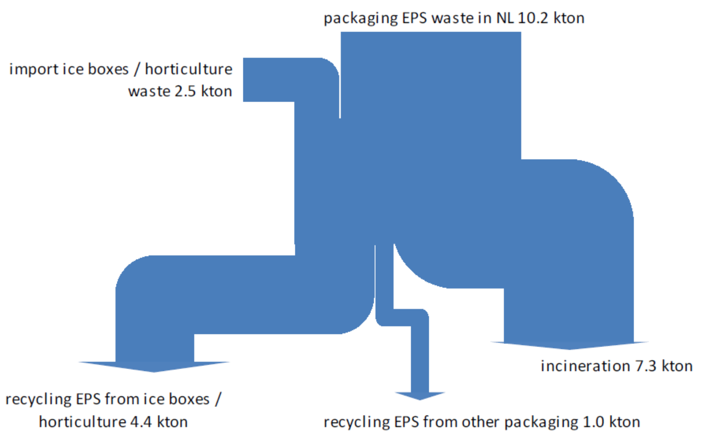
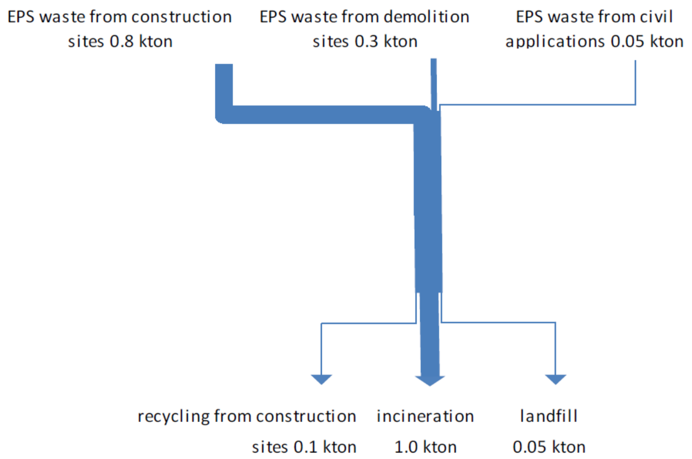


Figure 2.2: Yearly mass flow of construction EPS/XPS waste (2016)



Household Waste Recycling Centres (HWRCs) are an important link in the chain of collecting packaging EPS waste. Figure 2.3 briefly explains what a HWRC is and shows its various names in several EU countries.

Note that the above diagrams only show the mass flows in kilotons per year and therefore reveal nothing about stocks. As construction EPS has a much longer lifecycle than packaging EPS, the total existing stock of the former is much higher than that of the latter and presumably contains all the HBCDD still present in the Netherlands. This quantity is currently estimated to be 4,000 tonnes, compared to 35,000 tonnes in Germany [10].

Figure 2.3: Household Waste Recycling Centre (HWRC)

In the Netherlands, waste coming from households is accepted and processed by HWRCs. To HWRC sites, citizens separately bring several waste streams for disposal or recycling. The Dutch HWRCs typically collect approximately 20 different waste streams. In a growing number of HWRCs, EPS packaging waste is also collected separately.

Names for HWRCs in several EU countries:

- The Netherlands: *milieustraat, gemeentewerf, afvalinzamelstation, afvalbrengstation*
- France: *déchetterie*
- United Kingdom: *recycling depot, bottle bank, local civic waste collection point*
- Spain: *punto de reciclaje, ecoparque*
- Germany: *Wertstoffhof, Recyclinghof, Müllsammelstelle*

Picture 2.4: Impression of a typical HWRC (in Geleen, NL)

2.2 Correct use, recycling and disposal

The 2016 inventory concluded that there was insufficient data on the HBCDD content of EPS and XPS packaging, construction and demolition waste. Therefore, better identification of HBCDD-containing products and determination of their HBCDD concentrations are required to ensure that production, collection and recycling of EPS/XPS materials complies with the new regulations.

The three key research questions regarding correct use, recycling and disposal as defined in the project plan are [1]:

1. *Do all EPS/XPS products currently on the Dutch market contain less than 100 ppm HBCDD?*

2. *Do all EPS/XPS waste streams that are recycled contain less than 1000 ppm HBCDD?*

3. *Can all EPS/XPS waste streams with HBCDD content exceeding 1000 ppm be separated from other waste streams, and are they available for incineration or processing in the PolyStyreneLoop project?*

The aim of this project is to gain greater insight into actual concentrations of HBCDD in products and waste streams in the Netherlands and thus to answer these three questions. Annex IV of the POP Regulation limits HBCDD in POP waste to 1000 ppm. All waste materials above this limit must be treated in accordance with the Basel Convention. Annex 1 of the POP Regulation prohibits the marketing of substances, preparations and articles containing more than 100 ppm HBCDD.

2.3 Analysis techniques

To measure HBCDD content in EPS/XPS materials the three main options are:

1. **State-of-the-art laboratory techniques**

   Internationally standardised gas chromatography-mass spectrometry (GC-MS) or liquid chromatography-mass spectrometry (LC-MS) can be applied to a broad range of materials. These techniques detect the HBCDD component with a level of detection (LOD) of 10-100 ppm [3]. Sample preparation and analysis generally takes a few days. In most laboratories, the price per sample of these techniques is € 170-340 [3].

2. **X-ray fluorescence (XRF) spectroscopy**

   This technique can be used to detect the element bromine (Br) in products or raw materials. They are directly scanned; no samples are needed. Although the XRF scanner itself is expensive (approx. € 30,000), scanning is cheap (approx. € 10 per scan [3]) because measurement is direct and simple. XRF scanners are available as handheld devices with a bromine detection limit of approx. 10 ppm, which corresponds to approx. 14 ppm HBCDD [2]. XRF detects bromine and not HBCDD, though this technique may indicate the presence of HBCDD. Because new flame retardants that have replaced HBCDD are also brominated compounds, their presence is also indicated. XRF spectroscopy cannot distinguish between HBCDD and other brominated flame retardants, including the polymeric flame retardant PolyFR, which has been widely used as substitute for HBCDD in EPS/XPS products since 2015.

3. **X-ray fluorescence (XRF) spectroscopy including extraction**

   This new analysis technique (2014), developed by Fraunhofer (HBCD-IG) for rapid offline identification of the type of flame retardant present in EPS/XPS, uses XRF spectroscopy on EPS/XPS samples dissolved in acetone (2 g material in 5 g acetone) [2]. It can distinguish between the low-molecular-weight brominated flame retardants HBCDD, FR-720 and SR-130 that are soluble in acetone and the polymeric brominated flame retardant PolyFR that is barely soluble in acetone. The lower detection limit of this technique is approx. 50 mg of acetone-soluble brominated flame retardant per kg (= 50 ppm).

The main problem with this technique is that, as yet, insufficient validation and interlaboratory study is available and it has not been accepted as an international standard for the range of 100 ppm. Within the International Electrotechnical Commission (IEC) the method is validated for concentrations around 1000 ppm of HBCDD [12]. Another problem is that the UNEP Guidance for Analysis of POPs (2007) [4] states that the limit of quantification (LOQ, the lowest concentration that can be quantitatively determined with suitable precision) is 2 to 3 times the detection limit. For this technique the LOQ would be 100-150 ppm, which means that it is not very suitable for EPX/XPS product samples with close-to-maximum HBCDD concentration for products (100 ppm).

However, this technique's distinct advantages are that it is much simpler than LC-MS, it is quick (measurement results within 10 minutes) and the price per sample is much lower than LC-MS, which means that it could also be used by recycling companies. An exact price per analysis is not currently available but is estimated to be approximately € 20 per sample [3].

Because faster, more accurate and cheaper HBCDD analysis techniques are required, especially for lower concentrations, there is a programme for further development of such techniques, supervised by a working group of the International Electrotechnical Commission (IEC) [1]. Steering committee members have reported that the Polystyrene Loop initiative (www.polystyreneloop.eu) is simultaneously developing a cheap and simple test to determine the concentration of HBCDD in EPS/XPS foams.

3 MEASUREMENT PROGRAMME

3.1 Introduction

Making an inventory of HBCDD occurrence in EPS and XPS products and waste streams was a three-phase process with a cost- and time-efficient approach:

- Phase 1 – XRF spectroscopy, used to initially screen a large number of samples for brominated compounds;
- Phase 2 – XRF spectroscopy with extraction, used on the samples found to contain a brominated compound in order to determine whether it is soluble or insoluble;
- Phase 3 – LC-MS, used to accurately measure the HBCDD concentration in the samples shown to contain a soluble brominated compound (for details, see Subsection 4.3 below).

In Phase 1 all samples without bromine were discarded; in Phase 2 all samples without HBCDD or other soluble brominated flame retardants were discarded. In Phase 3, the remaining samples were checked for the presence of HBCDD, and its concentration was accurately measured. The results are presented in Figure 3.1

Figure 3.1: Detection of flame retardants in Phases 1, 2 & 3

composition	detection		
type of flame retardant	Phase 1 XRF screening	Phase 2 XRF with extraction	Phase 3 LC-MS
	positive on Br	positive on soluble Br	positive on HBCDD
HBCDD	yes	yes	yes
FR-720	yes	yes	no
SR-130	yes	yes	no
PolyFR	yes	no	no
no flame retardant	no	no	no

The measurement programme is described in greater detail in the following subsections.

3.2 Sampling strategy

The HBCDD measurement programme is based on the diagram in Figure 3.2 (below). For determination and measurement, the product and waste streams were divided into three categories:

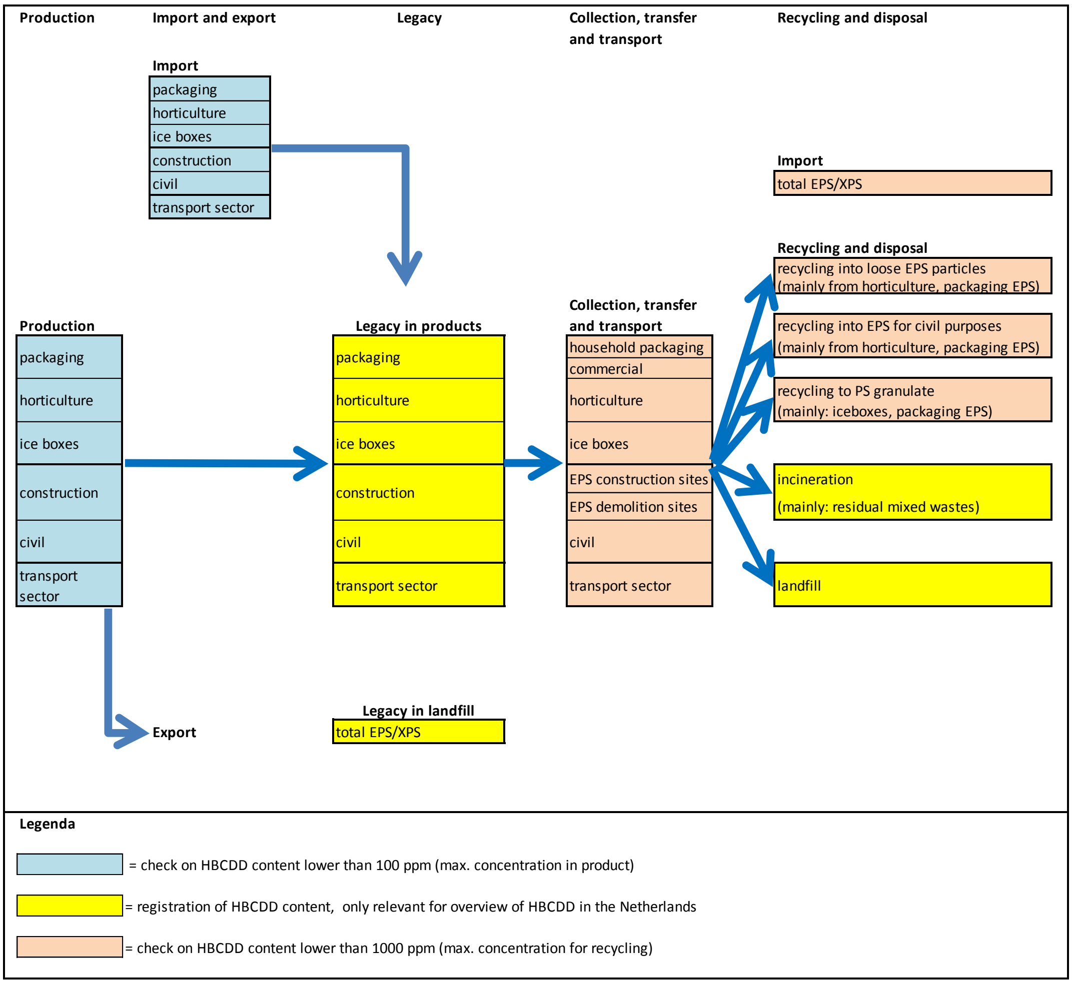
- *New or recycled products*
  In these materials the HBCDD concentration must be lower than 100 ppm (limit in accordance with Annex I of 850/2004/EC). In Figure 3.2 these materials are indicated in blue.

- *Waste streams for recycling*
  The HBCDD content in these materials must be below 1000 ppm. These materials are unsuitable for recycling and the HBCDD content must be destroyed if the

HBCDD concentration (as measured by the approved test procedure) exceeds 1000 ppm (low POP content in accordance with Annex IV of 850/2004/EC). In Figure 3.2 these materials are indicated in pink.

- *Materials in legacy and waste streams for disposal and energy recovery*
  There is no restriction on the HBCDD content of such materials. Their HBCDD content is only relevant for the total overview of HBCDD in materials in the Netherlands. In Figure 3.2 these materials are indicated in yellow.

Figure 3.2: Overview of EPS/XPS products and waste streams and the strategy for their measurement [1]



This project focused on:

- Domestically produced or import products (the blue items in Figure 3.2);
- Waste streams for collection, transfer, transport and recycling (the pink items in Figure 3.2).

Note that legacy products (the yellow items in Figure 3.2) are beyond the scope of this project, because these products are still in use and at that stage do not fall under the provisions of the Stockholm Convention and the EU POP Regulation.

Table 3.1 gives an overview of the threshold values for the various categories of material.

Table 3.1: Overview of threshold values for HBCDD per category of material

Category	Threshold value	remark
Legacy	None	
Import	<100 ppm	Allowed according to POP regulation Annex I
Production	<100 ppm	Allowed according to POP regulation Annex I
Waste[1]	< 1000 ppm	Non-POP waste
Waste[1]	> 1000 ppm	POP waste, has to be treated according to Basel convention (incineration, landfilling or a series of pre-treatments operations including volume reduction, size reduction, dissolution, sedimentation, and distillation and a subsequent destruction of HBCDD in hazardous waste incinerator).

1 = comprises collection, transfer and transport and recycling and disposal

To obtain an overview of the entire value and service chain of the EPS/XPS sector, measurements were made in the following successive lifecycle phases:

Import: all EPS/XPS material imported from other countries

Production: all EPS/XPS material produced in the Netherlands

Collection: all EPS/XPS waste

Recycling: all recyclates derived from EPS/XPS wastes

In addition to the lifecycle phases, we distinguish between the following applications:

- Packaging: Packaging of household appliances such as TVs and small domestic appliances, mostly made of EPS;
- Horticulture: EPS garden trays used in greenhouse cultivation;
- Icebox: EPS containers used to keep fresh products cool, usually in the fisheries sector;
- Construction: EPS or XPS insulation material used in buildings;
- Civil: EPS used in larger civil engineering infrastructure projects such as road and dike construction;
- Transport: various EPS applications as spare wheel holder or in vehicle doors.

In the production lifecycle phase there are two additional applications:

- Raw material (EPS beads): used to foam EPS;
- Specific product: EPS moulded products made to specifications.

The recycling lifecycle phase has three distinct categories, as presented in Table 3.2.

Table 3.2: Recycling categories

No.	Name	Recycling process
1	Loose particles	EPS waste is shredded and sieved into several fractions
2	EPS for civil purposes	EPS is heated and compacted into blocks
3	Polystyrene granulate	EPS waste is compacted, shredded, melted, filtered and formed into GPPS (general purpose polystyrene), a solid product in the form of mostly transparent solid granules

Table 3.3 (below) gives an overview of the number of samples taken from each lifecycle phase and the various EPS and XPS applications. Note the variation in the number of samples from successive lifecycle phases and different applications, which reflects the heterogeneity of uses of EPS and XPS. Only a few screening samples from iceboxes and garden trays were needed, because both those sectors use large numbers of identical products. In contrast, as EPS and XPS used for packaging or in construction were expected to show high variations in bromine content, a higher number of samples of those types of product were screened.

Table 3.3: Sampling for XRF screening

code	lifecycle phase	applications	Total no. of samples per lifecycle phase	XRF screening: no. of samples actual (-)	no. of locations actual (-)
1A	import	packaging	143	107	3
1B		horticulture		0	0
1C		ice box		18	1
1D		construction		8	4
1E		civil		0	0
1F		transport sector		10	1
2A	production	raw material (beads)	102	4	1
2B		packaging		22	3
2C		specific product		12	2
2D		horticulture		12	3
2E		ice box		7	2
2F		construction		41	6
2G		civil		4	1
2H		transport sector		0	0
3A	collection	packaging	837	493	5
3B		horticulture		4	2
3C		ice box		21	1
3D		construction		283	4
3E		civil		1	1
3F		transport sector		35	2
4A	recycling	loose particles	68	44	2
4B		civil		0	0
4C		PS granulate		24	1
Total				**1150**	**45**

Each of the XRF measurements has a unique and corresponding ‘reading number’, which is automatically generated by the scanner. A list of all the measurements is included in a separate document (HBCDD in polystyrene products and waste streams in the Netherlands – Measurement data). A summary of the results is presented in Section 4. The detailed guidelines for the XRF screening are presented in Annex 4.

In Phase 1, samples were quickly scanned for bromine using a Niton XL3t GOLDD+ handheld X-ray fluorescence (XRF) spectroscopic analyser (for specifications, see Annex 3).

The handheld XRF analyser measures the sample’s bromine concentration and displays the result. According to the literature, the level of detection (LOD) for XRF measurements is 10 ppm [3]. From this quick scan the presence of HBCDD cannot be concluded, though samples that may contain HBCDD can be selected for further analysis in Phases 2 and 3.

XTAC Analytical BV (XTAC) provided the necessary equipment and procedures for the XRF screening and measurement programme. The accuracy of XRF measurements increases with analysis time. To achieve statistically significant results, this investigation aimed to generate a large number of measurements. To make this possible within the available time, the analysis time was set to 15 seconds.

HBCD Industry Group provided standardised polystyrene pellet samples containing exactly 100 ppm and 1000 ppm HBCDD for calibration of the handheld XRF analyser.

3.3 Phase 1 – Initial screening by XRF spectroscopy

The XRF measurements indicate the bromine content of the samples. To connect these values to the HBCDD thresholds of 100 and 1000 ppm HBCDD the bromine concentrations have to be converted into HBCDD concentrations. Note that the conversion of a bromine concentration of a sample into a HBCDD concentration only makes sense if the sample contains HBCDD.

To convert the XRF analyser's bromine measurements into HBCDD concentrations, two standard samples were provided by the HBCD Industry Group[2], consisted of EPS beads containing exactly 100 and 1000 ppm HBCDD. The measurements of these samples are presented in Table 3.4, both on the original ppm scale and the Log10 transformed scale.

Table 3.4: XRF measurements (in ppm Br) of standard samples of 100 and 1000 ppm HBCDD

Original scale (ppm)		Logarithmic scale	
100 ppm	1000 ppm	100 ppm	1000 ppm
95.96	868.79	1.982	2.939
94.43	874.26	1.975	2.942
95.53	906.21	1.980	2.957
95.28	889.66	1.979	2.949

[2] European HBCD Industry Group of HBCD producers and users of polystyrene insulation foam, the major application of HBCDD. The HBCD producers are represented by EFRA (the European Flame Retardants Association) and HBCD users in the polystyrene insulation industry are members of PlasticsEurope (for expandable polystyrene) and Exiba (for extruded polystyrene).

Means and standard deviations (Sd) on both scales are presented in Table 3.5.

Table 3.5: Means an standard deviations of XRF measurement of standard samples

Standard sample	Original scale (ppm)		Logarithmic scale	
	Mean	Sd	Mean	Sd
100	95.3	0.644	1.979	0.002941
1000	884.7	16.827	2.947	0.008235

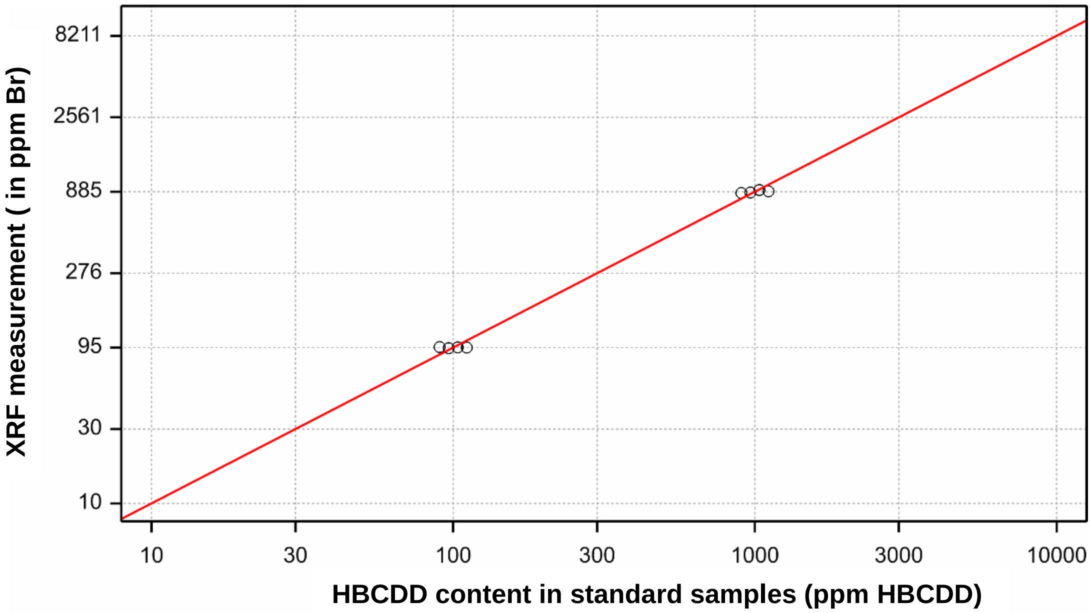
With regression analysis, the relation between the measurement and HBCDD concentration were calculated to be:

HBCDD concentration = 10 ^ [(Log10(Measurement) – 0.04375)/0.96767] (1)

The details of this calculation are presented in Annex 6.

A graphic presentation of this relation is presented in Figure 3.6.

Figure 3.6: Graphic presentation of relation between XRF measurement and HBCDD content in standard samples



3.4 Phase 2 – Determination by XRF spectroscopy with extraction

The main purpose of the Phase 2 measurements was to distinguish between acetone soluble and insoluble flame retardants in samples in which bromine had already been detected by XRF screening (Phase 1).

The Phase 1 results were used to select product and waste samples for Phase 2, based on the following criteria:

- Bromine concentrations exceeding the stipulated limits for HBCDD of 100 ppm for new products and 1000 ppm for waste;
- Uncertainty as to the type of brominated flame retardant present in the material.

The measurement programme for Phase 2 included 69 samples taken from:

- Imported packaging
- Imported construction products
- Imported materials used in the transport sector
- Waste material collected from the transport sector
- Recycling products (loose fill, fill for civil engineering applications and PS granulate).

In this phase, X-ray fluorescence spectroscopy with extraction [2] was used for sample measurements. This method, which was specially developed for EPS foams, requires that a 2-gram sample of EPS or XPS foam is treated with 5 grams of acetone for 5 minutes. The EPS or XPS foam shrinks in the acetone. The polystyrene polymer does not dissolve but forms a solvent-wet polymer gel and releases a polymer-free supernatant of acetone, which may contain the soluble brominated flame retardant. This supernatant is used for the XRF measurements in Phase 2.

If the brominated flame retardant is soluble, there will be a dilution factor between the measurements in Phase 1 and Phase 2. If the brominated flame retardant is fully soluble, all the bromine that was present in the 2-gram sample measured in Phase 1 will be present in the 5 grams of acetone measured in Phase 2. A sample that shows a bromine content of 1000 ppm in Phase 1 should give a bromine content of 2/5 x 1000 ppm = 400 ppm in Phase 2. Thus, the ratio between the measurements in Phase 2 and Phase 1 indicates how well the brominated compound in the sample dissolves in acetone.

The low-molecular-weight flame retardants HBCDD, SR-130 and FR-720 are soluble in acetone and can therefore be detected in the liquid phase, whereas high-molecular-weight flame retardants including PolyFR are insoluble and cannot be detected in the liquid Phase.

Analysis notes for the measurements using this technique are presented in Annex 5.

3.5 Phase 3 – Measurement of HBCDD content by LC-MS

All samples from Phase 2 containing a soluble bromine compound were selected for the Phase 3 measurement programme and were analysed by Bureau Veritas (see Annex 9 for details).

Liquid chromatography-mass spectrometry (LC-MS) was used to measure HBCDD concentration. The level of detection (LOD) for HBCDD was 10-100 ppm [3]. Note that this LOD is close to the threshold value of 100 ppm for substances, preparations and articles stated in the EU POP regulation (850/2004/EC).

4 RESULTS

This section discusses the results of Phase 1 (initial screening by XRF spectroscopy), Phase 2 (determination by XRF spectroscopy with extraction using acetone) and Phase 3 (LC-MS measurement of HBCDD concentration). Because of the large number of measurements in Phases 1 and 2 (1,150 and 69 respectively) the analytical data is presented in a separate report *HBCDD in Polystyrene Products and Waste Streams in the Netherlands – Analytical Data Phases 1 and 2*. The data from Phase 3 are presented in Annex 9.

4.1 Phase 1 – Initial screening by XRF spectroscopy

The summary statistics classified by lifecycle phase and application are presented in Table 4.1 (below). The last five columns on the right show the number of samples in the categories 0, 0-100, 100-1000, 1000-4000 and greater than 4000. Due to the large number of zeroes, the mean and standard deviation are not very informative.

The following sub-sections present histograms for the categories that have at least 10 samples and at least two significant values. The heading of each histogram shows the number of samples (N), the number of zero samples (N_0) and the number of positive samples (N_p).

Table 4.1: Summary statistics bromine concentration measured by XRF

Code	lifecycle phase - application	Summary statistics				Number of samples in range				
		N	Mean ppm	Sd ppm	Max ppm	0	0-100	100-1000	1000-4000	> 4000
1A	Import - Packaging	107	142	893	6653	98	2	5	-	2
1C	Import - Icebox	18	2	8	34	17	1	-	-	-
1D	Import - Construction	8	4417	782	5222	-	-	-	3	5
1F	Import - Transport	10	3	9	28	9	1	-	-	-
2A	Production - Raw Material	4	2444	2787	4906	1	1	-	-	2
2B	Production - Packaging	22	99	208	866	12	6	4	-	-
2C	Production - Specific product	12	2044	2167	4438	6	-	-	1	5
2D	Production - Horticulture	12	0	0	0	12	-	-	-	-
2E	Production - Icebox	7	0	0	0	7	-	-	-	-
2F	Production - Construction	41	4908	2064	8106	3	-	-	5	33
2G	Production - Civil	4	2967	1398	4953	-	-	-	3	1
3A	Collection - Packaging	493	589	1425	14182	377	14	17	63	22
3B	Collection - Horticulture	4	55	111	221	3	-	1	-	-
3C	Collection - Icebox	21	5	13	50	18	3	-	-	-
3D	Collection - Construction	283	2706	2982	18422	83	20	23	62	95
3E	Collection - Civil	1	3070	-	3070	-	-	-	1	-
3F	Collection - Transport	35	358	1212	5372	21	5	7	-	2
4A	Recycling - Loose Particles	44	1559	2453	9271	10	5	11	14	4
4B	Recycling - Granulate	24	83	71	210	-	15	9	-	-
	Total	**1150**	**n.a.**	**n.a.**	**n.a.**	**667**	**73**	**77**	**152**	**171**

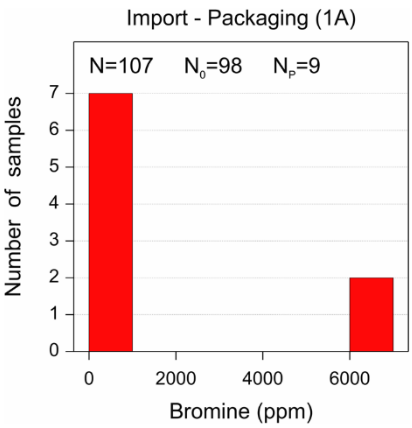
4.1.1 Import – Packaging (1A)

EPS is currently used as a packaging material for a wide range of domestic and/or office appliances. During XRF scanning (Phase 1), EPS was encountered as packaging for electrical and electronic products such as vacuum cleaners, washing machines, refrigerators, food mixers, coffee machines, TVs, laptops, printers and scanners. Measurements were done in the warehouses of three different stores selling such appliances.

For the vast majority of the 98 measurements (92%) no bromine was detected, whereas for nine measurements (8%) the XRF scanner did detect bromine (reading nos. 885, 888, 890, 1148, 1156, 1159, 1167 and 1180). In the case of the first two positive measurements we could take samples away for further analysis, though this was not allowed in the case of the other six positive measurements. Therefore, the same products were purchased at a later date, except one that was no longer available. The packaging materials of those five products were analysed, but no bromine was detected (reading nos. 1439, 1440, 1441, 1442 and 1443). This is probably because different producers manufacture EPS packaging for the same products.

Figure 4.2: Import – Packaging

Location(s)	3	
Total number of measurements	107	100%
No bromine detected	98	92%
Bromine detected	9	8%
Average measurement	142 ppm	
Lowest positive measurement	63 ppm	
Highest positive measurement	6653 ppm	
EPS	107	100%
XPS	0	0%



4.1.2 Import – Horticulture (1B)

EPS products for the horticulture sector are mostly garden trays. In the Netherlands, most vegetables are grown in greenhouses and little EPS is imported for this sector. Therefore, during Phase 1 it was difficult to do measurements on imported garden trays. However, this stream was analysed in other cycles (2D: Production – Horticulture and 3B: Collection – Horticulture). As garden trays have a short lifecycle, these measurements give a reliable insight into the results that would be expected for imported horticulture products, so no additional effort was made to locate imported EPS horticultural products for Phase 1.

4.1.3 Import – Icebox (1C)

At a fish auction, 18 measurements were conducted on ice boxes for fish, but only one was positive for bromine. As the detected level of bromine was well below 100 ppm, no sample was taken away.

Figure 4.3: Import – Icebox

Location(s)	1	
Total number of measurements	18	100%
No bromine detected	17	94%
Bromine detected	1	6%
Average concentration	2 ppm	
Lowest positive measurement	34 ppm	
Highest positive measurement	34 ppm	
EPS	18	100%
XPS	0	0%

4.1.4 Import – Construction (1D)

Eight measurements were done on material at three different markets for the construction industry and at a new building construction site. In each measurement, bromine was detected. The lowest concentration was 3347 ppm (reading no. 1447) and the highest 5222 ppm (reading no. 1203). Seven of the eight samples were from EPS plates and one from loose EPS pearls used for insulation.

Figure 4.4: Import – Construction

Location(s)	4	
Total number of measurements	8	100%
No bromine detected	0	0%
Bromine detected	8	100%
Average concentration	4417 ppm	
Lowest positive measurement	3347 ppm	
Highest positive measurement	5222 ppm	
EPS	8	100%
XPS	0	0%

4.1.5 Import – Civil (1E)

Civil infrastructure projects occur very occasionally. We were unable to find any such project. As major civil infrastructure projects are put out to tender, non-Netherlands companies who win a tender may import materials. The POP regulation prohibits import, marketing and use of POP-containing material.

4.1.6 Import – Transport (1F)

For the transport sector, measurements were done on the premises of a second-hand car vendor. Only one of these measurements detected bromine, though at a very low concentration of 28 ppm (reading no. 313). While it was initially thought that EPS would be used in the transport sector, a producer of products such as spare wheel support explained that instead of EPS, for foam applications EPP (expanded polypropylene) is mostly used. It is unclear whether the measurements done at the second-hand car vendor's were only on EPS or also on EPP. Different from EPS EPP does not contain HBCDD as a flame retardant.

Figure 4.5: Import – Transport

Location(s)	1	
Total number of measurements	10	100%
No bromine detected	9	90%
Bromine detected	1	10%
Average concentration	3 ppm	
Lowest positive measurement	28 ppm	
Highest positive measurement	28 ppm	
EPS or EPP	10	100%
XPS	0	0%

4.1.7 Production – Raw Material (2A)

At a single location, measurements were conducted on four bags of raw material for EPS production (EPS beads) Two bags contained flame retardants; the other two did not. For the former, the concentrations of flame retardant were high (4906 ppm, reading no. 772; 4809 ppm, reading no. 775). In one of the samples without flame retardant, a concentration of 62 ppm bromine was detected (reading no. 773).

Figure 4.6: Production – Raw Material

Location(s)	1	
Total number of measurements	4	100%
No bromine detected	1	25%
Bromine detected	3	75%
Average concentration	2444 ppm	
Lowest positive measurement	62 ppm	
Highest positive measurement	4906 ppm	
EPS	4	100%
XPS	0	0%

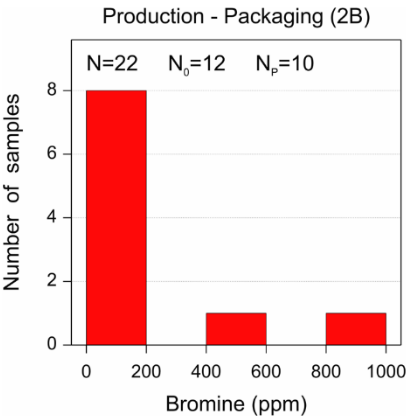
4.1.8 Production – Packaging (2B)

On the premises of three packaging producers various products were found. A total of 22 measurements were conducted, 10 of which showed significant concentrations of bromine. According to the producers, the product specifications do not require the use of EPS with flame retardants. The results show that more than half the products did not contain bromine. Of the 10 measurements that did detect bromine, eight were below 200 ppm. The two samples with higher concentrations were for the same product type (528 ppm, reading no. 837; 866 ppm, reading no. 838).

Bromine can be detected either due to on-site recycling of EPS or because silos previously used to produce construction materials required to contain brominated flame retardant were later used to produce packaging not required to contain bromine.

Figure 4.7: Production – Packaging

Location(s)	3	
Total measurements	22	100%
No bromine detected	12	55%
Bromine detected	10	45%
Average concentration	99 ppm	
Lowest positive measurement	40 ppm	
Highest positive measurement	866 ppm	
EPS	34	100%
XPS	0	0%

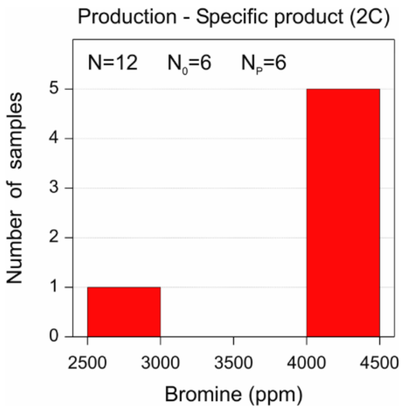


4.1.9 Production – Specific Product (2C)

At two locations, 13 measurements were conducted on specific EPS products that did not fall into other categories. These products included children's car seats, Christmas decorations, EPS ball floats and cisterns for toilets as well as boilers and other heating systems. Some of these specific products are required to contain flame retardant. The results below show that bromine was detected in six measurements.

Figure 4.8 –Production – Specific Product

Location(s)	2	
Total number of measurements	12	100%
No bromine detected	6	50%
Bromine detected	6	50%
Average concentration	2044 ppm	
Lowest positive measurement	2992 ppm	
Highest positive measurement	4438 ppm	
EPS	12	100%
XPS	0	0%



4.1.10 Production – Horticulture (2D)

Twelve measurements were conducted at three locations, but no bromine was detected.

Figure 4.9: Production – Horticulture

Location(s)	3	
Total number of measurements	12	100%
No bromine detected	12	100%
Bromine detected	0	0%
Average concentration	0 ppm	
Lowest positive measurement	-	
Highest positive measurement	-	
EPS	12	100%
XPS	0	0%

4.1.11 Production – Icebox (2E)

Seven measurements were conducted on ice boxes that had been produced at two different locations, but no bromine was detected.

Figure 4.10: Production – Icebox

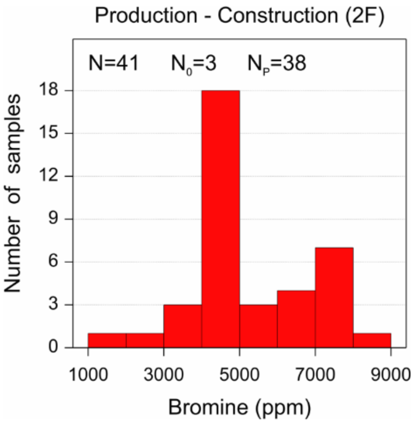
Location(s)	2	
Total number of measurements	7	100%
No bromine detected	7	100%
Bromine detected	0	0%
Average concentration	0 ppm	
Lowest positive measurement	-	
Highest positive measurement	-	
EPS	7	100%
XPS	0	0%

4.1.12 Production – Construction (2F)

A total of 41 measurements were conducted on the premises of six producers of construction material. In 38 of these measurements bromine was detected. Of the three measurements that detected no bromine, two measurements (reading nos. 116 and 117) were on the same product type and the weight of the end-product was noted as 170 grams. This seems low for a product for the construction sector, so the measurements may have been wrongly classified as construction EPS (i.e. it might have been an EPS product). For the third measurement (reading no. 1134) it was noted that it was white isolation material.

Figure 4.11: Production – Construction

Location(s)	6	
Total number of measurements	41	100%
No bromine detected	3	7.3%
Bromine detected	38	92.7%
Average concentration	4907 ppm	
Lowest positive measurement	1428 ppm	
Highest positive measurement	8106 ppm	
EPS	41	100%
XPS	0	0%



4.1.13 Production – Civil (2G)

At a single location, four measurements were conducted on products for civil engineering use. All four measurements detected bromine.

Figure 4.12: Production – Civil

Location(s)	1	
Total number of measurements	4	100%
No bromine detected	0	0%
Bromine detected	4	100%
Average concentration	2967 ppm	
Lowest positive measurement	1722 ppm	
Highest positive measurement	4953 ppm	
EPS	4	100%
XPS	0	0%

4.1.14 Production – Transport (2H)

No measurements were conducted on products for the transport sector. Initially, it was thought that more products for the transport sector would be made from EPS. During discussions with producers it was noted that most such products are made from EPP (expanded propylene).

4.1.15 Collection – Packaging (3A)

At four Household Waste Recycling Centres (HWRCs), 487 measurements were conducted. On the premises of a recycler, an additional six measurements were conducted on material that had come from a HWRC.

Due to the large number of samples it makes sense to consider the various types of sample, based on their appearance, as presented in Table 4.2.

Table 4.2: Collection of packaging types

Description	Appearance	No. of samples
Packaging (moulded parts)		**344**
Plate/construction	 	**107**

Description	Appearance	No. of samples
Horticulture		**2**
Unclear	 	**40**
Total		**493**

At HWRCs, EPS packaging waste is normally collected at one to three points in transparent bags of 1.0-1.4 m^3. Although only packaging EPS waste should be collected, Table 4.2 shows that EPS from construction, horticulture and other sectors is also collected, with construction waste being the biggest ‘foreign’ fraction. Of the 493 measurements conducted, 116 detected bromine in significant concentrations.

Figure 4.13: Collection - Packaging

Location(s)	5	
Total number of measurements	493	100%
No bromine detected	377	76%
Bromine detected	116	24%
Average measurement	589 ppm	
Lowest positive measurement	32 ppm	
Highest positive measurement	14182 ppm	
EPS	492	99.8%
XPS	1	0.2%
Packaging material	344 (35)*	70% (7%)*
Plates/Construction material	107 (74)*	22% (15%)*
Mix/other material or uncertain	42 (7)*	8% (1%)*

*numbers and percentages in brackets refer to the measurements that detected bromine.

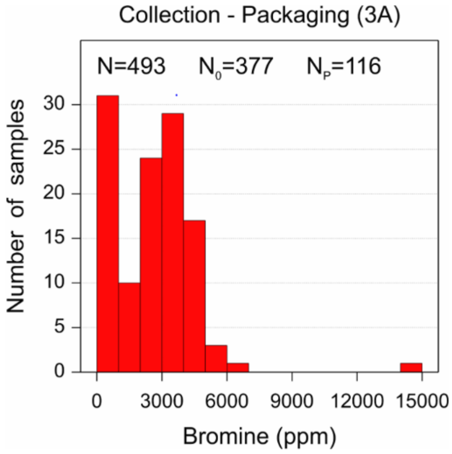


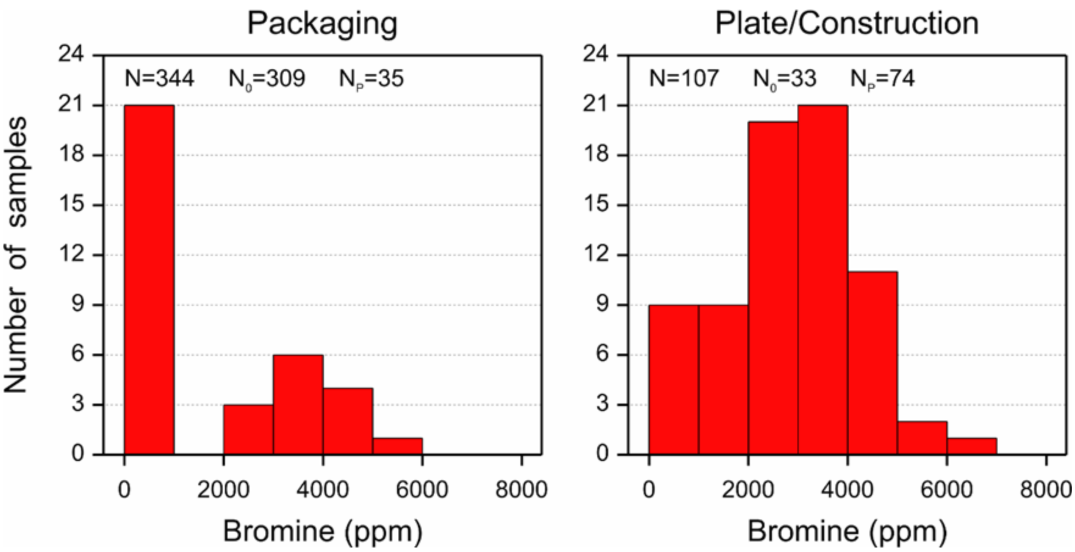
Figure 4.14 gives summary statistics of the different types of samples. The miscellaneous category includes two samples from horticulture, one from sculpturing and two unidentified samples.

Figure 4.14: Collection – packaging – summary statistics

Type of sample	Summary statistics				Number of samples in range				
	N	Mean	Sd	Max	0	0-100	100-1000	1000-4000	> 4000
Packaging	344	155	741	5524	309	12	9	9	5
Plate/Construction	107	2029	2086	14182	33	2	7	50	15
Miscellaneous	42	475	1238	4996	35	-	1	4	2

The large values in “Collection - Packaging” are thus mainly “Plate/Construction” type of samples. Histograms of the measured values for Packaging and Plate/Construction are given below.

Figure 4.15: Packaging and Plate/Construction types within Collection – Packaging



The weighted average[3] of all the measurements is 573 ppm bromine. If all the plate/construction measurements were removed, the average concentration would be 245 ppm.

Figure 4.16: Collection — packaging: total weighted concentration

Total weighted concentration	
Measurements	493
Total weight	70.1 kg
Total weighted concentration	40,153,358.2
Average weighted concentration	573 ppm

Figure 4.17: Collection — packaging: Weighted concentration without plate/construction types

Weighted concentration without plate/construction	
Measurements	386
Total weight	60.3 kg
Total weighted concentration	14,761,636.95
Average weighted concentration	245 ppm

4.1.16 Collection – Horticulture (3B)

At two locations, four measurements on collected horticulture material were conducted. One of these showed a bromine concentration of 221 ppm (reading no. 1444).

[3] For the weighted average, the total amount of HBCDD in the samples (in grams) is divided by the total weight of all samples (in grams).

Unlike other streams, there is no separate service for collection from the horticulture sector. When greenhouse cultivators have material to be discarded, they contact the recycler who then picks it up for recycling. Sampling from this stream was not possible during this project.

Figure 4.18: Collection – horticulture

Location(s)	2	
Total number of measurements	4	100%
No bromine detected	3	75%
Bromine detected	1	25%
Average concentration	55 ppm	
Lowest positive measurement	221 ppm	
Highest positive measurement	221 ppm	
EPS	4	100%
XPS	0	0%

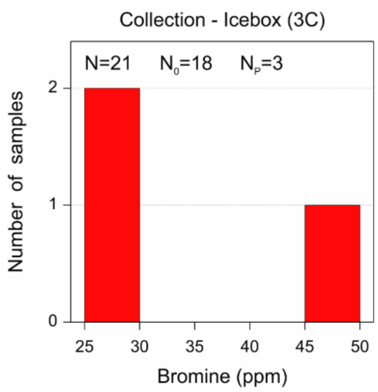
4.1.17 Collection – icebox (3C)

At a single location, a total of 21 iceboxes were screened. Of these, bromine was detected in only three samples and at very low concentrations, the highest being 51 ppm (reading no. 550).

As there is no dedicated service for collection of iceboxes, they are either directly collected by, or taken to, the recycler. Sampling large numbers of iceboxes was not possible during this project.

Figure 4.19: Collection – icebox

Location(s)	1	
Total number of measurements	21	100%
No bromine detected	18	86%
Bromine detected	3	14%
Average concentration	5 ppm	
Lowest positive measurement	25 ppm	
Highest positive measurement	50 ppm	
EPS	21	100%
XPS	0	0%

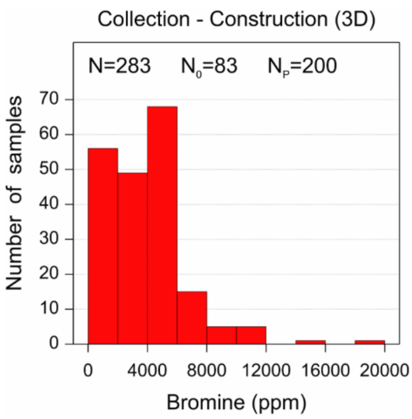


4.1.18 Collection – Construction (3D)

A total of 283 measurements were conducted at four construction sites. Bromine was detected in 200 of those measurements. The lowest detected concentration was 27 ppm (reading no. 814) and the highest was 18422 ppm (reading no. 1329). While this category was expected to yield data only on construction and demolition waste, packaging waste (most likely from businesses) was also found.

Figure 4.20: Collection – Construction

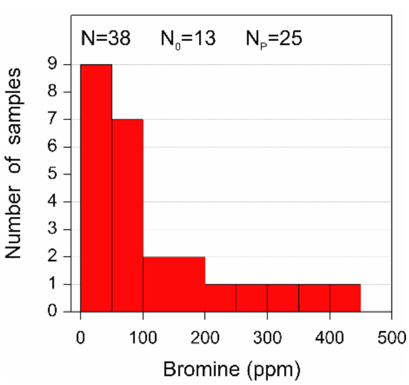
Location(s)	4	
Total number of measurements	283	100%
No bromine detected	83	23%
Bromine detected	200	77%
Average concentration	2706 ppm	
Lowest positive measurement	27 ppm	
Highest positive measurement	18422 ppm	
EPS	230	81%
XPS	12	4%
EPS/XPS[1]	38	13%
XPS/PUR[2]	3	1%



[1] All the measurements were conducted on the light-fine fraction from sorting installations (intermediate product).
[2] It is unclear whether this was XPS or PUR material

Within the category Collection – Construction, 38 measurements were conducted on the light-fine fraction from sorting installations (intermediate product). This is a fine mixture that remains after wind sifting and sieving. Due to its porosity and light weight, EPS often occurs in this fraction together with other materials. As Figure 4.2.1 (below) shows, compared to other measurements in the category Collection – Construction, the light-fine fraction from sorting installations shows zero or low concentrations of bromine. Of those with significant concentrations, over half are below 100 ppm.

Figure 4.21: Light-fine fraction from sorting installations (intermediate product)



4.1.19 Collection – Civil (3E)

It was difficult to conduct measurements on material used for civil engineering purposes. Only one such measurement was made, giving a bromine concentration of 3070 ppm (reading no. 1104), which suggests that this material contains a flame retardant as is to be expected in material of this category.

Figure 4.22: Collection – Civil

Location(s)	1	
Total number of measurements	1	100%
No bromine detected	0	0%
Bromine detected	1	100%
Average concentration	3070 ppm	
Lowest positive measurement	3070 ppm	
Highest positive measurement	3070 ppm	
EPS	1	100%
XPS	0	0%

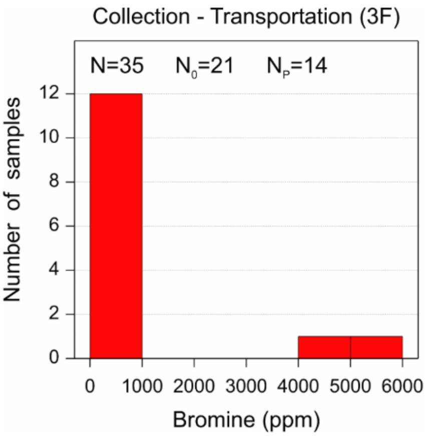
4.1.20 Collection - Transport (3F)

This category is the streams of EPS from the automotive and transport sectors, including cars, cooling trucks, caravans and boats. To gain insight into the stream of cooling trucks, caravans and boats, phone interviews with various stakeholders were conducted. Two of them informed us that in these sectors waste is usually shredded, sorted to extract valuable materials including ferrous and non-ferrous metals and then the rest is sent to landfill. To confirm this, three shredding companies in the Netherlands were contacted, and all of them stated that they do not treat the streams in question. What exactly happens to the stream of waste from boats, caravans and cooling trucks therefore remains unclear. After some discussion, it was assumed that these relatively small streams are most likely incinerated and that the potential for recycling is also rather small. Furthermore, as indicated in Subsection 4.1.6 (above), in the transport sector EPP is more frequently used than EPS.

For the stream coming from cars, a total of 35 measurements were conducted at two locations. Ten of these measurements were on the fraction of fibrous materials from shredded cars, which may contain EPS if that material is used in the cars. The other 25 measurements were conducted on used cars before shredding. Of the total of 35 measurements, 14 revealed significant concentrations of bromine, the lowest being 37 ppm (reading no. 860) and the two highest being 4980 ppm (reading no. 861) and 5372 ppm (reading no. 864). As the histogram shows, the majority of the significant measurements are below 1000 ppm.

Figure 4.23: Collection – Transport

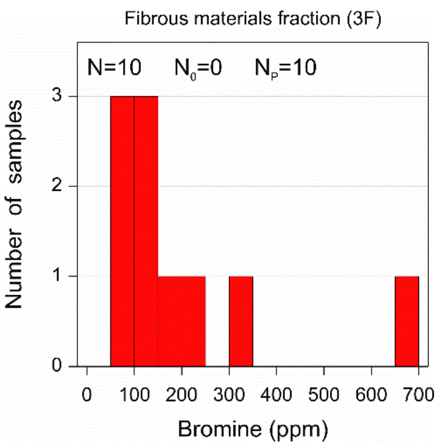
Location(s)	2	
Total number of measurements	35	100%
No bromine detected	21	60%
Bromine detected	14	40%
Average concentration	358 ppm	
Lowest positive measurement	37 ppm	
Highest positive measurement	5372 ppm	
EPS	1	3%
XPS	0	0%
PPO/PS	1	3%
EPS/EPP[1]	33	94%



[1] For some measurements it was difficult to identify the type of material, either because the measurements were done on the light fraction of shredded cars or because it was uncertain whether the material measured was EPP or EPS.

All ten measurements conducted on the fibrous materials fraction showed significant concentrations of bromine ranging between 82 ppm (reading no. 435) and 700 ppm (reading no. 429).

Figure 4.24: Fibrous materials fraction



4.1.21 Recycling – Loose Particles (4A)

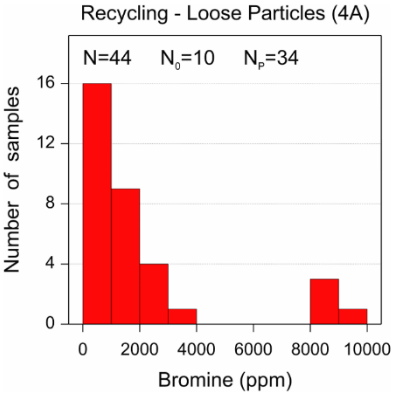
The term ‘loose particles’ refers to waste material that has been shredded for recycling and is available in various particle sizes. The particles are subsequently used for various applications including sitting bags and drainage material or as raw material for other products.

A total of 44 measurements were conducted at two locations. Of those, 34 showed significant concentrations of bromine ranging from 4 ppm (reading no. 445) to 9271 ppm (reading no. 449). 29 measurements were above the critical concentration of 100 ppm.

Note that in this category, measurements were also conducted on the premises of a recycler in Belgium, because two sites were needed and it proved difficult to do measurements at a second recycler in the Netherlands.

Figuree 4.25: Recycling – Loose Particles

Location(s)	2	
Total number of measurements	44	100%
No bromine detected	10	23%
Bromine detected	34	77%
Average concentration	1558 ppm	
Lowest positive measurement	4 ppm	
Highest positive measurement	9271 ppm	
EPS	44	98%
XPS	0	0%



4.1.22 Recycling – Civil (4B)

No measurements were conducted on recycled material from civil engineering demolition, as there was no such demolition during the project period.

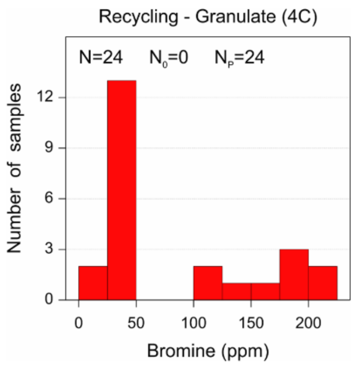
4.1.23 Recycling – PS Granulate (4C)

PS granulate is general-purpose polystyrene (GPPS) produced by suspension of a styrene polymer. GPPS is a solid product, supplies mainly in the form of transparent compressed granules.

At a single location, a total of 24 measurements were conducted on recycled PS granulate, all detecting bromine. As the histogram shows, nine measurements were above the critical concentration of 100 ppm.

Figure 4.26: Recycling – PS Granulate

Location(s)	1	
Total number of measurements	24	100%
No bromine detected	0	0%
Bromine detected	24	100%
Average concentration	83 ppm	
Lowest positive measurement	24 ppm	
Highest positive measurement	210 ppm	
Duration measurement	15 secs	
GPPS	24	100%



4.1.24 Weighted concentrations

For a large number of samples, their weight was also recorded. This can be used to calculate weighted means, as presented in figure 4.27 below.

Figure 4.27: Weighted concentrations

Code	Lifecycle Application	N	Mean	weighted Mean
1D	Import - Construction	8	4417	4659
2A	Production - Raw Material	4	2444	2538
2B	Production - Packaging	22	99	121
2C	Production - Specific product	12	2044	4024
2D	Production - Horticulture	12	0	0
2E	Production - Icebox	7	0	0
2F	Production - Construction	41	4908	6285
2G	Production - Civil	4	2967	*
3A	Collection - Packaging	493	589	573
3C	Collection - Icebox	21	5	2
3D	Collection - Construction	283	2706	3685
3F	Collection - Transport	35	358	752
4A	Recycling - Loose Particles	44	1559	1506

Note that the weighted means are larger than the unweighted means, which indicates that heavier samples generally have higher concentrations of bromine. However, note also that the weighted mean can be strongly influenced by a few samples, as is the case for Production - Specific product, which has the following data.

Figure 4.28: Weighted concentrations – example (production) – specific product

Weight	-	-	-	15	17	19	23	30	49	96	836	1412
Bromine	4116	4434	0	0	0	2992	0	4252	0	0	4302	4438

4.1.25 Stacked percentages

The histogram in Figure 4.29 (below) shows the stacked percentages of the Lifecycle – Application categories. The number of samples is indicated at the bottom of each histogram. Interesting remarks on the histogram are:

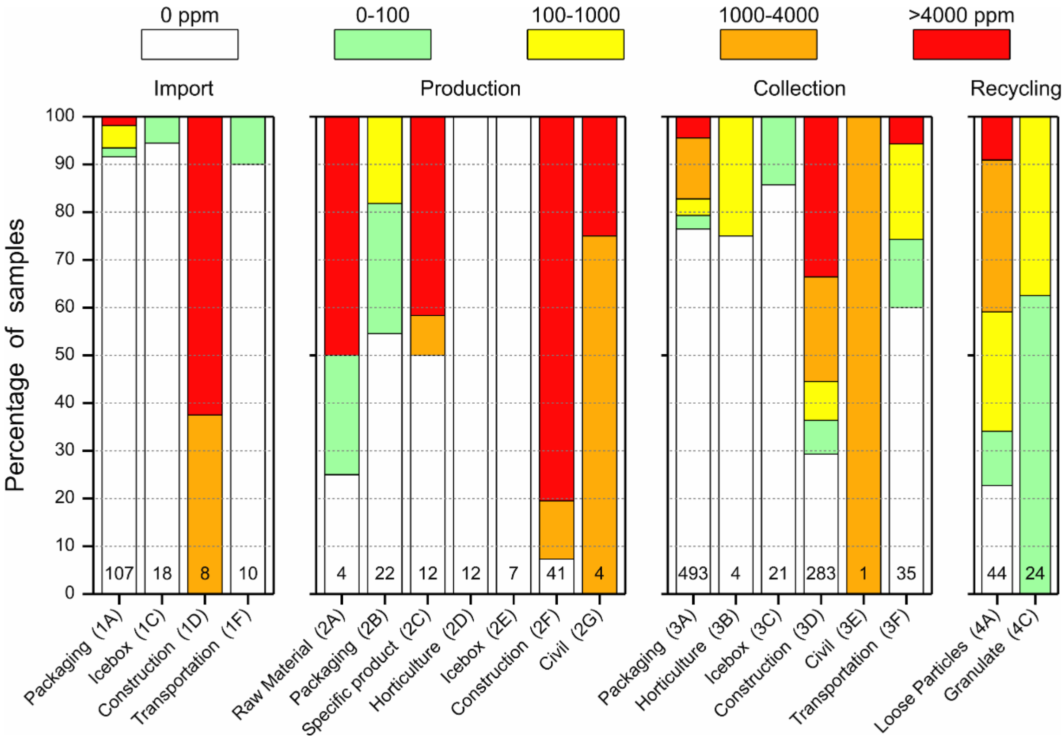
- In the Import lifecycle phase, the Construction application shows the highest number of samples with bromine concentrations between 1000 and 4000 ppm and above 4000 ppm. For imported packaging material, there were only a few measured concentrations between 100 and 1000 ppm and only one above 4000 ppm.
- In raw materials for EPS production, bromine was detected either in zero-to-very low or very high concentrations.

- In more than 80% of packaging materials, zero or very low concentrations of bromine were detected. In only a few cases were bromine concentrations between 100 and 1000 ppm detected.
- Roughly 50% of the specific products contained no bromine, while the others showed concentrations between 1000 and 4000 ppm or, mostly, above 4000 ppm.
- Horticulture products and iceboxes were found to be free of bromine.
- In over 90% of the products for construction, bromine was detected in high concentrations.
- In materials for civil engineering purposes bromine was always detected either between 1000 and 4000 ppm or above 4000 ppm.

The “Collection – Packaging” category not only includes packaging waste but also plate/construction waste. As Figure 4.29 shows, whereas no bromine was detected in about 78% of the measurements conducted, in the other 22%, bromine was detected for all the ranges shown in the figure. Surprisingly, although no bromine was detected in almost all the measurements conducted on production materials for the horticulture sector, one measurement (25%) detected a concentration between 100 and 1000 ppm. While the majority of collected iceboxes was also free of bromine, there were a few measurements in the range of 0-100 ppm. In the civil engineering category, over 70% of the measurements detected bromine in various concentrations, mostly in the range 1000-4000 ppm and above 4000 ppm. In the transport category, 60% of the measurements detected no bromine, though about 34% detected bromine in the ranges 0-100 ppm and 100-1000 ppm. In the remaining 6%, concentrations above 4000 ppm bromine were measured.

Finally, in the Recycling lifecycle phase we distinguish between loose particles and PS granules. For the loose particles, 33% of measurements showed no bromine or concentrations below 100 ppm, whereas the remainder detected higher concentrations. The majority, about 58%, were in the ranges 100-1000 ppm and 1000-4000 ppm. In the remaining 9%, bromine was detected in concentrations higher than 4000 ppm. In all the measurements conducted on PS granulate, bromine was detected. In about 63% of the measurements the bromine concentration was in the range of 0-100 ppm, whereas in the remaining 27% it was in the range 100-1000 ppm.

Figure 4.29 – Stacked percentages



4.2 Phase 2 – Determination by XRF spectroscopy with extraction

4.2.1 Selection of samples

To make the final selection of samples for Phase 2, three criteria were applied: bromine concentration as measured in Phase 1, availability and distribution. Only samples in which bromine concentrations exceeded 80 ppm were considered. Availability refers to whether sufficient material was available to conduct further testing. After applying the first two criteria, the remaining samples were further scrutinized. With regard to distribution, the aim was to adequately represent the different lifecycles and applications, the variability in the different categories, and the various locations where samples were collected. In Phase 2, in addition to analysis of the two standard samples for calibration, 69 samples were analysed. For reading numbers 520 (Collection – Construction), 550 (Collection – Icebox) and 784 (Recycling – Granulate), although bromine concentrations lower than 80 ppm were detected, those samples were still used for Phase 2 in order to satisfy the third criteria. See Annex 8 for a table indicating the planned and executed Phase 2 measurement programmes.

4.2.2 Interpretation of measurements

As described above in Subsection 3.4, the Phase 2 analyses were expected to result in bromine concentrations of approximately 40% for brominated compounds with high solubility in acetone and close to zero for those of very low solubility in acetone.

The P2/P1 ratio – i.e. the Phase 2 measurement (by XRF spectroscopy with extraction) divided by the Phase 1 measurement (by direct XRF spectroscopic scanning) – was used to interpret the results of Phase 2, as follows:

1. P2/P1 > 20% high solubility
2. P2/P1 > 2% and < 20% intermediate solubility
3. P2/P1 < 2% low solubility

High solubility indicates the presence of a low-molecular-weight flame retardant: HBCDD, FR-720 or SR-130. Low solubility indicates the presence of the high-molecular-weight flame retardant PolyFR.

Intermediate solubility probably indicates the presence of a combination of high and low-molecular-weight flame retardants.

In some cases, the Phase 2 measurements correlated weakly with those in Phase 1 (see Subsections 4.2.3 and 4.2.4 below), for example:

- Some Phase 2 measurements yielded P2/P1 values above 40%, which can only be explained by measurement artefacts.
- The Phase 2 measurements of the standard samples for calibration yielded unexpectedly and inexplicably low bromine concentrations (see Subsection 4.2.3 below).

As previously explained, the Phase 2 measurement results were used only to assess the solubility in acetone of the detected bromine compound. The P2/P1 ratios and the factors that may have influenced them were not further investigated.

4.2.3 Measurement of standard samples

Table 4.3 shows the results of the measurements conducted on the standard samples.

Table 4.3: Results of Phase 1 and Phase 2 measurements on standard samples

Description	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Standard sample 100 ppm HBCDD	95	11	12.0%	intermediate
Standard sample 1000 ppm HBCDD	885	113	12.8%	intermediate

These measurement results were lower than expected. As the HBCDD in the samples should dissolve well in acetone, the P2/P1 ratio should be approximately 40%. We suspect that the beads had not been completely transformed into a solvent-wet gel at the time of the measurements, probably because the method of XRF spectroscopy with extraction that was used [2] was developed for EPS foams. The method uses a standard 5 minutes of contact between the sample (foam) and the acetone. However, as the EPS beads of the standard samples are not foam but solid, their transformation into a solvent-wet gel could have taken longer than is the case for foam. This theory was confirmed by measuring the supernatant of the standard samples after one week of contact with acetone, these results of which are presented in Table 4.4.

Table 4.4: Results of Phase 1 and Phase 2 measurements on standard samples — Phase 2: after one week of contact with acetone

Description	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction after 1 week (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Standard sample 100 ppm HBCDD	95	30	31.1%	high
Standard sample 1000 ppm HBCDD	885	299	33.8%	high

4.2.4 Measurement of selected EPS and XPS samples

Imported EPS
Table 4.5 shows the results of the measurements conducted on the selected samples from imported packaging and construction EPS.

Table 4.5: Results of Phase 1 and Phase 2 measurements on samples of imported EPS

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Import	Packaging	885	6653	12	0.2%	low
		888	6445	32	0.5%	low
		890	87	29	32.9%	high
	Construction	1202	4495	8	0.2%	low
		1203	5222	13	0.2%	low
		1139	3653	6	0.2%	low
		1340	4988	9	0.2%	low
		1341	5068	10	0.2%	low
		1447	3347	6	0.2%	low

These results show that, except for the sample measured in reading no. 890, none of the samples contained HBCDD or another low-molecular-weight flame retardant. The bromine in these samples is in a compound that is insoluble in acetone. Sample 890 was selected for LC-MS analysis in Phase 3.

EPS products
Table 4.6 shows the results of the measurements conducted on the selected samples from EPS material produced in the Netherlands.

Table 4.6: Results of Phase 1 and Phase 2 measurements of samples from EPS material produced in the Netherlands

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Production	Raw	772	4906	2	0.0%	low
	Packaging	837	528	2	0.3%	low
		847	4252	4	0.1%	low
		1123	4438	3	0.1%	low
		1128	165	0	0.1%	low
		1138	4630	7	0.1%	low
	Construction	88	4972	15	0.3%	low
		99	4788	10	0.2%	low
		134	5161	9	0.2%	low
		135	2556	861	33.7%	high
		843	7790	15	0.2%	low
		1113	5619	65	1.2%	low
		1137	4785	7	0.2%	low
		1136	4154	9	0.2%	low
	Civil	1110	2385	379	15.9%	intermediate
		1114	1722	418	24.3%	high

These measurements show that, except for the samples measured in reading nos. 135, 1110 and 1114, none of the samples contained HBCDD or another low-molecular-weight flame retardant. The bromine in these samples is in a compound that is insoluble in acetone. Three samples (reading nos. 135, 1110 and 1114) were selected for LC-MS analysis in Phase 3.

Collected EPS and XPS waste
Table 4.7 shows the results of the measurements conducted on the selected samples of collected EPS and XPS waste.

Table 4.7: Results of Phase 1 and Phase 2 measurements on collected EPS and XPS waste samples

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Collection	Packaging	230	301	74	24.6%	high
		261	5066	1722	34.0%	high
		216	130	0	0.1%	low
		167	3143	41	1.3%	low
		172	4381	65	1.5%	low
		615	151	41	27.2%	high
		350	3063	1	0.0%	low
		400	3580	1896	53.0%	high
		408	4653	1560	33.5%	high
		980	112	81	72.7%	high
		996	2988	4	0.1%	low
		469	14182	5677	40.0%	high
		1062	439	0	0.0%	low
	Horticulture	1444	221	66	30.0%	high
	Icebox	550	50	10	19.4%	intermediate
	Construction	478	3312	9	0.3%	low
		489	3390	3	0.1%	low
		520	64	8	13.2%	intermediate
		522	4246	1599	37.7%	high
		1374, 1380, 1385, 1386, 1387, 1388	1381	122	8.8%	intermediate
		1204	4863	1670	34.3%	high
		1232	8059	2901	36.0%	high
		1208	5601	11	0.2%	low
		823 (827)	407	not detectable		
		1426	6960	30	0.4%	low
		1427	5596	7	0.1%	low
		1285	11067	87	0.8%	low
		1296	3474	3	0.1%	low
	Civil	1101	3986	13	0.3%	low
		1104	3070	8	0.2%	low
	Transport	426	242	not detectable		
		431	156	not detectable		
		861	4980	1549	31.1%	high

These measurements show that, in some cases, the bromine present in collected EPS and XPS waste is in acetone-soluble brominated compounds. Of the 33 samples analysed, 15 had intermediate or high solubility of the brominated compound. Three samples (reading nos. 823, 426 and 431) could not be measured in Phase 2. These samples contained so much fluffy materials that no supernatant was available.

Nearly all the samples with intermediate or high acetone-solubility of the brominated compound, as well as the three samples that could not be measured in Phase 2, were selected for LC-MS analysis in Phase 3. The only exceptions were the samples corresponding to reading nos. 980 and the mix from 1374, 1380, 1385, 1386, 1387, 1388, which were of insufficient mass for Phase 3 measurement.

Recyclates
Table 4.8 shows the results of the measurements conducted on the selected samples from recyclates of EPS and XPS waste.

Table 4.8: Results of Phase 1 and Phase 2 measurements of samples from recyclates of EPS/XPS waste

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Phase 2/Phase 1 ratio (%)	Solubility of bromine component
Recycling	Loose Particles	769	916	165	18.0%	intermediate
		754	3517	32	0.9%	low
		771	2245	218	9.7%	intermediate
		752	583	7	1.1%	low
		760	211	24	11.3%	intermediate
		454	8833	157	1.8%	low
		468	616	28	4.6%	intermediate
		460	8352	150	1.8%	low
	PS granulate	799	209	13	6.4%	intermediate
		784	41	0	0.2%	low
		780	135	2	1.7%	low

These measurements show that, in some cases, the bromine present in recyclates of EPS and XPS waste is in acetone-soluble brominated compounds. In 5 of the 11 samples analysed, the brominated compound was of intermediate solubility.

All samples containing a brominated compound of intermediate or high acetone-solubility, as well as the three samples that could not be measured in Phase 2, were selected for LC-MS analysis in Phase 3.

4.3 Phase 3 – Measurement of HBCDD content by LC-MS

4.3.1 Selection of samples

Almost all the samples that in Phase 2 were found to contain a brominated compound of intermediate or high solubility in acetone – which indicates that HBCDD or another low-molecular-weight flame retardant is present – were analysed by liquid chromatography-mass spectrometry (LC-MS) in Phase 3. The only samples that fulfilled this criteria in Phase 2 but were not analysed in Phase 3 were the sample corresponding to reading no. 980 and the mixture of small samples in the category Collection – Construction (wind sifting 20-80 mm, mixture of reading no. 1374, 1380, 1385, 1386, 1387, 1388), as these two samples were of insufficient mass. In addition to the two standard samples of 100 and 1000 ppm HBCDD, 28 measurements were conducted in Phase 3.

4.3.2 Interpretation of measurements

Measurement by LC-MS allows a reasonably reliable conclusion to be drawn regarding the HBCDD concentration in the samples analysed. However, as shown by the results for the standard samples with 100 ppm and 1000 ppm HBCDD (see Tables 4.9 and 4.10), LC-MS does not detect all the HBCDD.

Table 4.9 shows the ratio between the results of Phase 3 (LC-MS analysis) and those of Phase 1 (initial screening with an XRF scanner). From the ratios it can be concluded that, in a range between 71% and 132% the screening via XRF does give reliable results for the concentration of HBCDD. It is important to note, again, that the XRF screening in Phase 1 only approximately measures the bromine concentration but does not allow a conclusion to be drawn regarding the type of brominated compound that is present.

Table 4.9: Comparison of Phase 1 and Phase 3 results

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 3 - LC-MS (ppm)	Phase 1/Phase 3 ratio (%)	Sample information
Import	Packaging	890	87	222	39%	packaging of Vogels floor stand for Sonos speaker
Production	Construction	135	2556	<10	no or not only HBCDD	EPS plate for construction
	Civil	1110	2385	<10	no or not only HBCDD	EPS plate, colour black/white, road construction application
		1114	1722	33	no or not only HBCDD	EPS 60, colour black/white, road construction application
Collection	Packaging	230	301	270	111%	EPS packaging collected at household waste recycling centre
		261	5066	5280	heterogeneous sample	EPS plates colleced at household waste recycling centre
				198	heterogeneous sample	
				6270	heterogeneous sample	
		615	151	183	82%	EPS packaging collected at household waste recycling centre
		400	3580	5030	71%	EPS plate with black dots collected at household waste recycling centre
				4750	75%	
		408	4653	4380	106%	EPS plate collected at household waste recycling centre
		469	14182	18100	78%	XPS sample bulky waste from companies and households
	Horticulture	1444	221	238	93%	heavily polluted garden tray
	Icebox	550	50	<10	no or not only HBCDD	producer is Knauf, Spain
	Construction	520	64	<10	no or not only HBCDD	EPS sample bulky waste from companies and households
				<10	no or not only HBCDD	
		522	4246	4280	99%	EPS sample bulky waste from companies and households
		1232	8059	17100	heterogeneous sample	wind sifting fraction 80-250 mm from sorting installation
		823 (827)	407	215	heterogeneous sample	sieving sand from sorting installation
	Transport	426	242	<10	no or not only HBCDD	light fraction shredder waste
		431	156	<10	no or not only HBCDD	light fraction shredder waste
		861	4980	6448	77%	EPS part, Citroen C2, year of constr. 2005
Recycling	Loose Particles	769	916	526	no or not only HBCDD	from mixed packaging material
		771	2245	540	no or not only HBCDD	from mixed packaging material
		760	211	56	no or not only HBCDD	from mixed packaging material
		468	616	27	no or not only HBCDD	from mixed packaging material
	PS granulate	799 (797)	209	<10	no or not only HBCDD	from ice boxes
Standard sample 100 ppm HBCDD			95	72	132%	
Standard sample 1000 ppm HBCDD			885	785	113%	

4.3.3 Measurement of standard samples

The first round of measurements using LC-MS gave unexpected results: no HBCDD was detected in the standard samples of 100 ppm and 1000 ppm HBCDD. This revealed an error in the analysis method, which was corrected before the analysis was repeated.

Table 4.10 shows the results of the measurements conducted on the standard samples in all three phases.

Table 4.10: Results of Phase 1, Phase 2 and Phase 3 measurements on standard samples

Description	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Result Phase 3 - LC-MS (ppm)
Standard sample 100 ppm HBCDD	95	11	72
Standard sample 1000 ppm HBCDD	885	113	785

Whereas the standard samples contain 100 ppm and 1000 ppm HBCDD, the Phase 3 results show that only approximately 75% of the HBCDD was detected by the LC-MS analysis used by Bureau Veritas (inhouse method, see Annex 9).

4.3.4 Measurement of selected EPS and XPS samples

Imported EPS
Table 4.11 shows that in reading no. 890, LC-MS measured 222 ppm HBCDD, which exceeds the 100 ppm HBCDD limit for products. It is important to note how rare this finding was. Of the 107 measurements conducted in Phase 1, in over 90% of the samples no bromine was detected with the XRF scanner. Out of the three XRF measurements in Phase 2, only one showed HBCDD, and only in a very low concentration. In the other two samples, the brominated compound was not HBCDD.

Table 4.11: Results of Phase 1, Phase 2 and Phase 3 measurements on samples of imported EPS

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Result Phase 3 - LC-MS (ppm)	Sample information
Import	Packaging	890	87	29	222	packaging of Vogels floor stand for Sonos speaker

EPS products
From the Phase 3 results for EPS products it can reasonably be concluded that HBCDD is no longer used in the production sector in the Netherlands. The three selected samples shown to contain an acetone-soluble brominated compound in Phase 2 did not contain HBCDD (see Table 4.12). It is therefore likely that these samples contained one of the other two soluble flame retardants: FR-720 or SR-130.

Table 4.12: Results of Phase 1, Phase 2 and Phase 3 measurements on samples of EPS material produced in the Netherlands

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Result Phase 3 - LC-MS (ppm)	Sample information
Prodution	Construction	135	2556	861	<10	EPS plate for construction
	Civil	1110	2385	379	<10	EPS plate, colour black/white, road construction application
		1114	1722	418	33	EPS 60, colour black/white, road construction application

Collected packaging waste
The results for packaging waste collected at HWRCs indicate that material identified as such contains HBCDD in lower concentrations than material identified as plate/construction waste. However, these results confirm that visual sorting of the waste is not sufficient. For example, reading no. 261 confirms that material that was considered to be of the same product origin clearly was not, considering the varying results obtained.
It should be noted that all the brominated compound that was found in collected EPS and XPS waste from HWRCs was HBCDD. All the samples shown to contain an acetone-soluble brominated compound in Phase 2 tested positive for HBCDD in Phase 3 (see Table 4.13).

Collected EPS waste from horticulture and ice boxes
Of the 16 measurements conducted on materials produced for, and collected from, the horticulture sector during Phase 1, in only one heavily polluted product did the XRF scan detect a brominated compound. LC-MS analysis in Phase 3 confirmed that the sample had an HBCDD concentration of 238 ppm. As this was an anomalous finding, and given the short lifecycle of the material in such applications, it is reasonable to conclude that EPS waste from the horticulture sector do not contain HBCDD (see Table 4.13).

All collected samples of ice boxes tested negative for HBCDD, from which it can be concluded that such products are generally free of HBCDD (see Table 4.13).

Collected construction waste

The conclusion regarding collected construction waste is that half the measured samples contained HBCDD in concentrations far above 1000 ppm (see Table 4.13). It is important to note that the sample corresponding to reading nos. 823 and 827 was heterogeneous: it contained a number of other materials from demolition waste. As the sample corresponding to reading no. 823 was no longer available for Phase 3, the sample corresponding to reading no. 827 was selected as being representative of sample 823 because it came from the same source.

Transport sector

Two of the three measurements of materials from the transport sector were conducted on a heterogeneous light fraction from a shredder. The Phase 3 analysis shows that these samples did not contain HBCDD (see Table 4.13). Interestingly, one of the rare EPS samples from the transport sector that was found did contain a high concentration of HBCDD. Strictly speaking, in the treatment chain, the sample corresponding to reading no. 861 would end up in the heterogeneous light fraction of a car shredder. From all this, we can reasonably conclude that the amount of HBCDD in waste from the transport sector is very low.

Table 4.13: Results of Phase 1, Phase 2 and Phase 3 measurements on collected EPS and XPS waste samples

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Result Phase 3 - LC-MS (ppm)	Sample information
Collection	Packaging	230	301	74	270	EPS packaging collected at household waste recycling centre
		261	5066	1722	5280	EPS plates colleced at household waste recycling centre
					198	
					6270	
		615	151	41	183	EPS packaging collected at household waste recycling centre
		400	3580	1896	5030	EPS plate with black dots collected at household waste recycling centre
					4750	
		408	4653	1560	4380	EPS plate collected at household waste recycling centre
		469	14182	5677	18100	XPS sample collected at household waste recycling centre
	Horticulture	1444	221	66	238	heavily polluted garden tray
	Icebox	550	50	10	<10	producer is Knauf, Spain
	Construction	520	64	8	<10	EPS sample bulky waste from companies and households
					<10	
		522	4246	1599	4280	EPS sample bulky waste from companies and households
		1232	8059	2901	17100	wind sifting fraction 80-250 mm from sorting installation
		823 (827)	407	n.d.	215	sieving sand from sorting installation
	Transport	426	242	n.d.	<10	light fraction shredder waste
		431	156	n.d.	<10	light fraction shredder waste
		861	4980	1549	6448	EPS part, Citroen C2, year of constr. 2005

Recyclates

Given that a large percentage of the packaging waste is recycled into loose particles, and considering that the Phase 3 results for collected packaging waste at HWRCs showed that HBCDD is still found in such waste, it is not surprising that the Phase 3 analysis of samples of loose particles also detected HBCDD (see Table 4.14). Note how the samples vary: two were found to contain just over 500 ppm of HBCDD, whereas two others were found to contain less than 100 ppm. The reason for the lower concentrations may be that a more homogenous input material was used (for example, only garden trays).

For PS granulate from ice boxes as the main input stream, the conclusion is that it does not contain HBCDD and therefore no follow-up is required (see Table 4.14). Note that the sample corresponding to reading no. 799 was no longer available for Phase 3. However, as the sample corresponding to reading no. 797 came from the same big bag of PS granulate, it can be assumed that the latter is representative of the former.

Table 4.14: Results of Phase 1, Phase 2 and Phase 3 measurements on samples of recyclates of EPS/XPS waste

Life Cycle Phase	Application	Reading Number	Result Phase 1 - XRF screening (ppm)	Result Phase 2 - XRF with extraction (ppm)	Result Phase 3 - LC-MS (ppm)	Sample information
Recycling	Loose Particles	769	916	165	526	from mixed packaging material
		771	2245	218	540	from mixed packaging material
		760	211	24	56	from mixed packaging material
		468	616	28	27	from mixed packaging material
	PS granulate	799 (797)	209	13	<10	from ice boxes

5 CONCLUSIONS

The results from the measurements in the Phases 1, 2 and 3 from this investigation have led to the following conclusions:

Measurement techniques
- XRF screening detects brominated flame retardants effectively;
- XRF with extraction distinguishes between PolyFR and other flame retardants;
- Cost and lead time of LC-MS measurement of HBCDD in EPS/XPS restrict its usefulness for everyday operations.

Regarding HBCDD in EPS iceboxes and horticulture products
- EPS from ice boxes and horticulture products does not contain HBCDD.

Regarding HBCDD in EPS packaging material
- New packaging materials do not contain HBCDD;
- Packaging EPS collected from household waste recycling centres (HWRCs) is contaminated with construction EPS and XPS;
- A small part of packaging EPS on HWRCs contains HBCDD.

Regarding HBCDD in construction material
- Some newly domestically produced EPS products contain other flame retardants (FR-720 of SR-130) with similar acetone-solubility to HBCDD;
- Construction material collected from demolition sites generally contains HBCDD in concentrations above 1000 ppm;
- The light-fine fraction from sorting installation (an intermediate product) may contain HBCDD concentrations above 100 ppm.

Regarding HBCDD in transportation sector
- The occurrence of HBCDD in the transportation sector is very low.

Regarding HBCDD in EPS recyclates
- Loose particles may contain HBCDD concentrations above 100 ppm;
- Polystyrene granulate from ice boxes does not contain HBCDD.

These conclusions are described in more detail in the following subsections.

5.1 Measurement techniques

XRF screening
The XRF screening in Phase 1 has shown that XRF measurements are effective in detecting bromine that occurs in brominated flame retardants used in EPS products and wastes. The measurements conducted on standard samples showed that repeated measurements had similar results. The lowest results showed that the XRF detection limit for bromine in EPS is below 10 ppm. Not only is XRF screening cheap (approx. € 10 per measurement), but the measurement results are generated quickly (15 seconds analysis duration) and the screening is non-destructive.

For samples shown to contain HBCDD, the XRF measurement corresponds closely to the HBCDD concentration as measured by LC-MS (for details, see Subsection 4.3 above).

XRF measurement with extraction

XRF measurement with extraction distinguishes effectively between the low-molecular-weight flame retardants that are soluble in acetone and the high-molecular-weight flame retardant that is not soluble in acetone. In this investigation, however, results were influenced by measurement artefacts. The precise nature of these artefacts and how they influenced the results was beyond the scope of this investigation.

XRF measurement with extraction is relatively cheap (approx. € 20 per measurement) and measurement results can be generated relatively quickly (within 10 minutes).

LC-MS measurements
The laboratory results showed that sample preparation including extraction for HBCDD measurements by LC-MS is a complex process. Only 75% of the HBCDD in the standard samples was detected using Bureau Veritas' in-house method.
A distinct advantage of the LC-MS method is that it specifically measures HBCDD concentration. However, this method has two serious disadvantages: its high price of € 170-340 per sample (see Subsection 2.2 above) and its lead time of several days, which make it too expensive and impractical for everyday use.

5.2 No HBCDD in EPS ice boxes and horticulture products

In general samples of import, production and recycling of horticulture products (garden trays) and iceboxes do not contain HBCDD.

5.3 HBCDD in packaging EPS

The results from the investigation show that new packaging materials do not contain HBCDD. A small part of the imported and produced packaging material contains a brominated flame retardant in the form of PolyFR. No indication was found that the flame retardants FR-720 and SR-130 are used in packaging material.

Calculations on the samples that were collected from the household waste recycling centers (HWRCs) show that the average bromine content in the packaging EPS from HWRCs (493 samples) is 573 ppm (see Subsection 4.1.15, Table 4.16, above). Assuming all of the brominated compound were HBCDD this quantity can be calculated to be 638 ppm HBCDD using the equation (1) from Subsection 3.3.1.
The amount of brominated compound in the packaging EPS from HWRCs can be lowered to 245 ppm if construction waste (plated materials) is kept separate. Assuming the brominated compound in the remaining packaging EPS would all be HBCDD this quantity can be calculated to be 265 ppm HBCDD using the equation (1) from Subsection 3.3.1.

Although the overall results from the investigation show that the variation in the measurements make it difficult to assess the exact HBCDD concentration in a certain type of material there is a strong indication that packaging EPS waste collected from HWRCs has a HBCDD content that is considerably higher than 100 ppm. Even if construction EPS and plate materials are kept separate from the packaging EPS waste, they will still have an HBCDD concentration exceeding the limit of 100 ppm.

In the next few years, HBCDD concentrations in packaging EPS at HWRCs will decrease because HBCDD has been phased out and the lifecycle of packaging EPS is short (on average, approximately 6 months) [1]. That no HBCDD was detected in recently produced packaging material strongly indicates that this prediction is valid.

5.4 HBCDD content in EPS and XPS construction materials

Import and production
All of the samples from imported or nationally produced construction EPS contained a brominated compound. Most construction EPS was found to contain PolyFR. Only one sample of construction material and two samples of EPS for civil purposes were found to contain a soluble flame retardant other than HBCDD (FR-720 or SR-130).

Collection
Approximately 70% of the EPS/XPS samples collected from construction and demolition waste contained brominated flame retardants in concentrations higher than 1,000 ppm. However, approx. 30% of the samples from construction and demolition showed lower concentrations of bromine. The most likely explanation for this finding is that some of the EPS/XPS in construction and demolition waste is packaging waste.
Approximately 4% of the construction and demolition waste samples were XPS. The light-fine fraction from sorting installations (an intermediate product) was found to have an HBCDD concentration of 215 ppm. This result indicates that the presence of HBCDD is a problem if (some of) this intermediate product is processed into recyclates that enter the market. Because only one measurement was conducted on this heterogeneous material, more measurements are needed for a firm conclusion to be drawn.

5.5 No HBCDD in transport sector

The occurrence of HBCDD in the transport sector is very low (see Subsection 4.3.4 above).

5.6 HBCDD in recyclates

Loose particles
Some of the recyclates in the form of loose particles contain HBCDD concentrations above 100 ppm. Concentrations below 100 ppm were found, possibly as the result of a more homogenous input material (for instance only garden trays).

PS Granulate
The polystyrene granulate produced from ice boxes does not contain HBCDD.

5.7 Wrap up - Answers to the three central questions

This subsection presents the answers, based on the results of this investigation, to the three most important questions regarding correct use, recycling and disposal of EPS/XPS products (see Subsection 2.1, above):

1. *Do all EPS/XPS products currently put on the Dutch market contain less than 100 ppm HBCDD?*

   The answer here is a clear yes.

2. *Do all EPS/XPS waste streams that are recycled contain less than 1000 ppm HBCDD?*

The answer to this question is also yes. In some cases – most importantly that of the household waste recycling centres – a fraction of the material that is recycled contains more than 1000 ppm HBCDD. However, this result is due to unintended contamination. In general, the average HBCDD concentration of the waste streams that enter the recycling process is below 1000 ppm.

3. *Can all EPS/XPS waste streams with HBCDD content exceeding 1000 ppm be separated from other waste streams and are they available for incineration or the PolyStyreneLoop project?*

   The answer to this question is no. Separating EPS/XPS waste containing more than 1000 ppm HBCDD from other waste requires effort, takes time and can only partially succeed.
   This investigation has shown that construction EPS collected at HWRCs generally contains more than 1000 ppm of some brominated compound, which may be HBCDD. Although such construction EPS can be collected separately at HWRCs and kept separate from other waste, this is a new practice that would not be easy to implement.
   For construction EPS from demolition sites, which generally contains more than 1000 ppm HBCDD, the current practice is that it is mixed with the rest of the demolition waste. Although such construction EPS can be collected separately at demolition sites, this would require that the demolition sector adopt a new workflow, which requires a complicated change process.

6 RECOMMENDATIONS

Based on the measurements of bromine and HBCDD in the three phases of this investigation and the conclusions presented in the previous section the following recommendations to the Ministry of Infrastructure and Water Management are formulated:

1. *Inform EPS packaging waste recyclers of the legal requirement that only products and materials containing less than 100 ppm HBCDD are permitted on the market.*
   This investigation has shown (1) that a fraction of the material that is collected as packaging waste for recycling still contains HBCDD and (2) that some recyclates from EPS packaging waste have HBCDD concentrations higher than 100 ppm. Annex 1 of the EU POP regulation (850/2004/EC) prohibits the marketing of substances, preparations and articles with HBCDD concentrations exceeding 100 ppm. Since recycling of packaging EPS is common practice in the Netherlands and this investigation had revealed that the HBCDD concentration in some recyclates may exceed this legal limit, recyclers of EPS packaging waste must be made aware of the need to stay under the limit.

2. *Inform the management of HWRCs on the importance of separating packaging EPS from construction EPS*
   This investigation has shown that packaging EPS waste collected at HWRCs includes some construction waste. Construction EPS from demolition sites contains HBCDD and is often contaminated with non-plastic materials including sand and concrete. The management of HWRCs should be made aware that it is important not to mix construction EPS and plate EPS with separately collected packaging EPS. Developing and distributing a waste-management guideline on how to distinguish between packaging EPS and construction EPS would be a helpful step towards this goal.
   It should be noted that the concern to keep these two types of EPS separate is shared with the 'Packaging Waste Fund' (*Afvalfonds Verpakkingen*), the Dutch collective of producers and importers of packaging materials. The Dutch Packaging Waste Fund financially compensates those municipalities that are responsible for managing HWRCs for their collection of packaging EPS. However, the Fund does not intend to contribute financially to the collection of construction EPS.

3. *Repeat HBCDD measurement on EPS packaging collected from HWRCs*
   At this moment part of the packaging EPS that is collected from HWRCs contains HBCDD. Because HBCDD is no longer used in EPS and the lifecycle of packaging EPS is short, the HBCDD content in this waste stream is likely to decline quickly. A yearly repetition of the measurement of HBCDD in EPS waste from HWRCs will reveal when the HBCDD concentration in this waste stream is low enough.

4. *Request that producers and importers of packaging EPS reduce the use of flame retardants in their EPS packaging.*
   The EU's POP Regulation strictly limits HBCDD in substances, preparations and articles to 100 ppm. EPS that is collected for recycling should be free of HBCDD as far as is possible. XRF screening has proven to be effective in measuring bromine concentrations and is the only practicable option for day-to-day measuring of HBCDD concentrations in incoming EPS packaging waste. The LC-MS option is too expensive and time-consuming.

Continued use of brominated flame retardants in packaging makes XRF screening of incoming EPS waste less effective. If other brominated flame retardants continue to be used in packaging materials, XRF screening will exclude those materials from the recycling process, thus limiting the amount of EPS waste that can be recovered and reused.

7 LITERATURE

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[12] International Electrotechnical Commission – TC111, Determination of certain substances in electrotechnical products – Part 3-1: Screening electrotechnical products for lead, mercury, cadmium, total chromium and total bromine using X-ray Fluorescence Spectrometry, Available at: http://www.iec.ch/

Annex 1 - Project Plan "Inventory of concentrations of HBCDD in a number of waste streams"

"Inventory of concentrations of HBCDD in a number of waste streams" (kenmerk 31133033)

In 2013 the flame retardant HBCDD was added to the UN Stockholm Convention. As a result, production and use were prohibited and waste containing HBCDD should be treated in such a way that the HBCDD is destroyed or irreversibly transformed. 95% of the HBCDD currently used in the Netherlands is present in expanded polystyrene (EPS) and extruded polystyrene (XPS) products.

In 2016 Giraf Results made an inventory of size and value of HBCDD in EPS and XPS waste streams, assuming most of the HBCDD being present in construction EPS. The report resulted in an overview on expanded polystyrene (EPS) and extruded polystyrene (XPS) products and waste streams. Therefore, it was concluded that the new Dutch waste management policy plan (known as LAP-3) should provide for separate collection and recycling of HBCDD free packaging EPS and prevent contamination with packaging EPS that does contain HBCDD.

The study further concluded that little is known about the quantities and the HBCDD content of EPS and XPS packaging waste produced by the commercial sector (which consists mainly of HBCDD-free packaging EPS) and construction and demolition waste (which consists mainly of HBCDD-containing EPS/XPS).

Information is also lacking on how these wastes are treated and what the prospects for improvement are. Therefore, further investigation of these two waste streams was recommended.

Literature studies showed that legacy products placed on the market in the past, imported EPS products and certain EPS packaging material may include HBCDD-containing EPS/XPS and could be placed on the market after collection and recycling. Therefore, better insight into HBCDD concentrations and identification of products that contain HBCDD is required to ensure that production, collection and recycling of EPS/XPS materials conforms to the new regulations for HBCDD in materials. This is particularly true for the packaging EPS resulting from household waste recycling centers and the commercial sector. Unless separated before, HBCDD-containing EPS could contaminate these waste streams and render them unsuitable for recycling and placing on the market again in articles.

To ensure that production, collection and recycling of EPS/XPS materials conforms with the new regulations for HBCDD in materials, screening and measurements of HBCDD concentrations in the various product and waste streams are needed. This is especially important for imported EPS products and EPS packaging material destined for recycling, that may include HBCDD-containing EPS/XPS, and are meant for placing on the market.

The objective of this project is to get more insight in actual concentrations in the six principal waste streams identified in the 2016 report. This information is relevant in the context of the new national waste management plan as well as in the context of placing articles on the market in compliance with Annex I of the EU POP Regulation.

Central question is:
What is the actual concentration of HBCDD in the various product and waste streams as identified in the report of Giraf Results?

The three central questions for correct use recycling and disposal are:

1. Do all EPS products on the Dutch market have a HBCDD content below 100 ppm?

2. Do all EPS waste streams that are used for recycling have a HBCDD content below 1000 ppm?

3. Can all EPS waste streams with a HBCDD content above 1000 ppm be separated from other waste streams and are they available for incineration or the PSL project (a promising recycling solution for waste construction EPS/XPS materials containing HBCDD)?

The project should deliver a reply to the central question. The reply should be based on screening and on measurements of concentrations. The result should be representative for the 6 waste streams in abovementioned report.

Inventory of concentrations of HBCDD in a number of waste streams

The report will provide an overview of actual concentrations of HBCDD in 6 waste streams. The report will have 2 objectives:

The first objective is to provide information relevant to be able to decide in the new waste management plan on the structure of collection and recycling of the relevant materials. The objective is to have a better idea what these results will mean for the waste treatment options in the Netherlands, including the perspective for the PSL project that industry will start in 2018. The result is relevant in the context of the national waste management plan (known as LAP-3).

The second objective is to inform the international community in Brussels (EU colleagues of chemicals and waste) and in Geneva (Representatives of the Basel and Stockholm Convention) about the results of this project, in combination with the 2016 report of Giraf Results.

Annex 2 - Steering committee and external contributions

The steering committee that was formed for this project is presented in Table A2.1.

Table A2.1: Steering committee

No.	Organisation	Name
1	Ministry of Infrastructure and Water Management, NL – The Hague	Mr C. Luttikhuizen (Chairman)
2	Ministry of Infrastructure and Water Management, NL – The Hague	Mr P. Frijns
3	RIVM, NL – Bilthoven	Mr M.P.M. Janssen
4	Eumeps, B – Maaseik	Mr E. Meuwissen
5	Synbra Technology B.V., NL – Etten-Leur	Mr J. Noordegraaf
6	ICL-IP, NL – Amsterdam European HBCD Industry Group - Brussels	Mr L. Tange
7	Stybenex, NL - Nijmegen	Mr H. E. Las

A list is of the external contributions to this project is presented in Table A2.2.

Table A2.2: External contributions

Nr.	Organisation	Description of contribution	Name
1	XTAC Analytical B.V., NL - Voorschoten	Rental XRF scanner type Niton XL3t GOLDD+, training of XRF measurements, analyses of with XRF including extractive method	Mr R. van Hilten
2	Wageningen University Research, NL – Wageningen	Statistical analysis of measurement data	Mr P. Goedhart
3	Bureau Veritas, D - Hamburg	Analyses with liquid chromatography – mass spectrometry (LC-MS)	Mr H. Hinrichs
4	HBCD Industry Group (through Versalis), I - Mantova	Provision of samples of EPS beads containing exactly 100 ppm and 1000 ppm HBCDD	Mr L. Nannetti (Versalis)

Annex 3 – Specifications XRF Analyser Niton XL3t GOLDD+

Thermo Scientific Niton XL3t GOLDD+ Series Analyzers

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The chart below details the sensitivity, or limits of detection (LODs)[1] of the Niton XL3t GOLDD+ Series for specific polymer matrices. LODs are calculated as three standard deviations (99.7% confidence interval) for each element for a 30-second total analysis time.

Limits of detection (LODs) are dependent on the following factors:

- Testing time
- Interferences/matrix
- Level of statistical confidence

Please Note:
Ongoing research and advancements in our Niton XL3t GOLDD+ analyzers will lead to continual improvement in many of the values detailed in this chart. Contact a Thermo Fisher Scientific office or your local representative for the latest performance specifications.

Actual analysis time is based on your requirements, and, in most cases, shorter times will give you the detection limits you require. For example, if analysis time was reduced from 60 seconds to 15 seconds, then the detection limits obtained would be double the value. Similarly, increasing the analysis time will reduce the detection limits by the square root of the increased time.

Limits of Detection in ppm (mg/kg)

	Time	30s / filter	
	Matrix	**PE**	**PVC**
Elements	**Ba**	100	N/A
	Sb	22	25
	Sn	18	20
	Cd	13	15
	Bi	5	20
	Pb	5	15
	Br	3	8
	Se	3	20
	As	3	18
	Hg	6	30
	Au	8	40
	Zn	12	70
	Cu	12	60
	Ni	12	75
	Fe	20	120
	Cr	12	20
	V	200	1100
	Ti	10	50
	Cl	40	N/A

Element list shown is not exhaustive. For limits of detection for elements not shown, please contact a Thermo Fisher Scientific office or your local representative.

N/A = Not applicable

1. *Definition and Procedure for the Determination of the Method of Detection Limit,* 40 CFR, Part 136, Appendix B. Revision 1.11. U.S. Environmental Protection Agency. U.S. Government Printing Office: Washington, DC, 1995.

AN44829 07/2010

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Annex 4 - Guidelines for the XRF screening of products and waste streams

1. XRF measurements of EPS/XPS overall

- Do as much as possible random sampling.
- Measure standardized test samples as system check at the beginning and end of each day.
- Before measuring the sample, weigh it. They should ideally at least weigh 50 g in case further analysis is needed.
- Take a few pictures of the samples and the place where they were found.
- Before taking the measurements note in the XRF the location.
- If possible place the samples on the aluminium plates before doing the measurements (protection against radiation).
- At the same time you are doing the measurements also write down the required information on the data sheet.
- Only take samples along in which you detected bromine of a critical level (anything above 90 ppm)
- Put a sticker on the samples you take along for possible further analysis. On the sticker state the sample number, name of the location, date and possibly weight, result and type of material.
- Also write the sample number with permanent marker on the sample.
- Put all the samples you are taking along in one bag. Put a sticker on the bag with date and location.

2. Measurement of EPS/XPS from import and production samples

- In consultation with the shops/producers: (1) open the packaging, (2) measure from the packaging or (3) measure from the packaging brought back from clients after installations.
- Every time: measure and note down result and specifications of product (brand, type, origin, number ID). For (3) see how to note specifications of product.
- If bromine measured and possible take along a sample.

3. Measurement of EPS/XPS samples from collection at household waste recycling centers (milieustraten)

- Methodology:
  - Take one full bag that has been stored in the container.
  - Open bag and sort plates from forms.
  - Find the plates and the forms of EPS/XPS that go together.
  - Take a picture of all the contents of the bag sorted.
  - Weigh those that belong to each other, measure and write down weight and result.
  - If bromine is measured above a critical level take along for further analysis.
  - The rest fraction in the bag that could not be sorted or is too small, weigh together. From this fraction randomly select 5 samples for measurement. If bromine measured, take sample along even if too light.
  - Once done continue with next bag (select the bags randomly)
  - Continue until you have at least 100 measurements.
  - Make sure to always measure the whole bag.

4. Measurement of EPS/XPS samples from collected waste streams

- see under 1. XRF measurements of EPS/XPS overall
- in addition for construction waste: go through waste pile and select as much EPS/XPS as possible and then do measurements

5. Measurement of EPS/XPS samples from recycling

- fill ziplock bags with loose particles and measure later on tripod.
- Follow methodology steps as described under 1. XRF measurements of EPS/XPS overall

Annex 5 - Analysis notes XRF measurements using extractive method

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NL-2254 AE VOORSCHOTEN
Tel.+31-(0)71-5317874
Fax.+31-(0)71-5763852
E-mail info@xtac.nl

Subject: Br analysis in Polystyrene using ED-XRF

Analysis Notes to results submitted 29-01-2018

Summary:

The samples have been analysed after following sample preparation:
2,00 +- 0,01 gram polystyrene sample has been added to a plastic sample bottle containing 5,00 +- 0,05 g acetone.
In most samples the polystyrene formed a gel at the bottom of the bottle.
After minumum of 5 minutes the liquid phase was poured into a XRF sample cup.
The sample cup was analysed using ED-XRF.
The results are reported as obtained by the ED-XRF aparatus.

Equipment used:
100 ml plastic beaker with lid.
Acetone analysis grade.
Balance (1 mg accuracy).
XRF sample cups 32 mm.
X-ray film for sample cup: Polypropylene 6um.
ED-XRF settings 30 sec main filter only plastics mode (FXL).

Remarks:
Some samples could not be analysed because there was no liquid separated.
Sample 823, 426, 431

Annex 6 – Relationship between XRF measurement and HBCDD

For the calibration of the XRF measurements two standard samples were provided by the HBCD Industry Group[4]. These two standard samples consisted of EPS beads containing exactly 100 and 1000 ppm HBCDD. The following measurements of these standard samples with 100 and 1000 ppm HBCDD are available, both on the original ppm scale and the Log10 transformed scale.

Original scale (ppm)		Logarithmic scale	
100 ppm	1000 ppm	100 ppm	1000 ppm
95.96	868.79	1.982	2.939
94.43	874.26	1.975	2.942
95.53	906.21	1.980	2.957
95.28	889.66	1.979	2.949

Means and standard deviations (Sd) on both scales are as follows:

Standard sample	Original scale (ppm)		Logarithmic scale	
	Mean	Sd	Mean	Sd
100	95.3	0.644	1.979	0.002941
1000	884.7	16.827	2.947	0.008235

Based on this small set, a relationship has been derived between the measured ppm values and the true values. It is evident that the measurement error on the original scale is not constant; the variability in the measurements at 1000 ppm is much larger than at 100 ppm. A logarithmic transformation stabilizes the variances. An F-test, see e.g. https://en.wikipedia.org/wiki/F-test_of_equality_of_variances, reveals that the null-hypothesis of equal variances at the log-scale cannot be rejected (F-value 7.84, p-value 0.125). This is why a regression analysis on the log-scale has been conducted.

There are just two values for the standard samples, 100 and 1000 ppm, and based on these two values a general relationship has to be established. Many relationships are possible, but since there are only two standard values, it is impossible to discriminate between relationships. It has therefore been assumed that there is a constant multiplicative factor *F* between a measurement at a true value of *Z* ppm, and at a true value that is 10 times as high, i.e. 10×*Z* ppm. The following simple regression model meets this assumption:

$$\text{Log10(Measurement)} = \alpha + \beta \,\text{Log10(StandardValue)} \quad (1)$$

The constant multiplicative factor then equals $F = 10^{\beta}$. Estimates for the regression parameters α en β, and their standard errors are as follows:

Parameter	estimate	s.e.	t(6)	t pr.
α	0.04375	0.0111	3.93	0.008

[4] The European HBCD Industry Group gathers HBCD producers and users in the polystyrene insulation foam sector, the major application of HBCD. The HBCD producers are represented by EFRA (the European Flame Retardants Association) and the HBCD users in the polystyrene insulation industry are members of PlasticsEurope (for expandable polystyrene) and Exiba (for extruded polystyrene).

β	0.96767	0.00437	221.33	< 0.001

The estimated factor F the equals 9.2825, and this is almost equal to the ratio (9.2836) of the mean measurement at 1000 ppm (884.7) and at 100 ppm (95.3). Note that the parameter α is significantly different form zero with p-value 0.008. Predicted values according to this model are as follows:

Standard	1	10	100	1,000	10,000
Prediction	1.11	10.27	95.30	884.6	8,211

Note that predicted values at true values of 1 and 10 ppm are above the true value, while predictions at larger true values are below the true value. An alternative model, which also meets the assumption of multiplicatively, is given by (1) with $\alpha = 0$. Then by definition the mean measurement at a true value of 1 ppm equals 1 ppm. The estimate of β then equals 0.9845, giving *F* = 9.649. predictions under this alternative model are as follows:

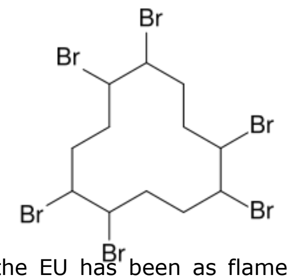
Standard	1	10	100	1,000	10,000
Prediction	1.00	9.65	93.11	898.4	8,669

The mean measurements at 100 and 1000 ppm are, under this model, somewhat worse represented. Note that the difference between the two models is rather small for true values up to 10,000 ppm. There are only eight measurements which are larger than 10,000, the largest measurement being 18,422 ppm.
Because there is not a large difference between the regression model with and without the constant α, and because the estimate of the constant α is significantly different from zero, we choose to use the model which includes the constant α. This implies that the following back-transformation has been used[5]:

Value = 10 ^ [(Log10(Measurements) – 0.04375)/0.96767] (2)

[5] Technical note: the value in equation (2) should be multiplied by $\exp(\sigma^2/2)$, with σ^2 de estimate of the residual variance of the fitted regression model (1). However, since model (1) fits the data extremely well, the estimate of σ^2 is close to zero, such that $\exp(\sigma^2/2)$ is very close to one. This factor is therefore disregarded.

Annex 7 – List of used terms

Term	Definition, explanation
Waste*	All substances, preparations or articles that the holder discards, intends to discard or must discard. *: Environmental Management Act
Waste incineration plant (AVI)	A waste incineration plant established primarily for the incineration of mixed municipal waste (Both R1 and D10 plants). In practice these are the 12 plants that may be eligible for R1 status based on the footnote to the R1 operation of Annex II of the Waste Framework Directive.
Construction and demolition waste	Waste released during the construction, renovation and demolition of buildings and other constructions, including those in civil engineering.
EPS	Expanded polystyrene (EPS) is foamed product made out of polystyrene beads through a foaming process. Polystyrene is (PS) is a synthetic aromatic polymer made from the monomer styrene.
FR-720	TetrabromobisphenolA,Bis(2,3-dibromopropyl ether), $C_{21}H_{20}Br_8O_2$ (943.2 g/mol) FR-720 is an additive flame retardant containing both aromatic and aliphatic bromine.
Waste separation	Collection where a waste stream is kept separated as to type and nature of the waste in order to facilitate a particular treatment.
Hazardous waste *	Waste that have one or more of the hazardous properties listed in Annex III to the Waste Framework Directive. Explanation: This abstract definition comes from the Environmental Management Act. In the Netherlands this has been included in the 'European Waste Catalogue Regulation' and 'Waste Catalogue (Integral Text) Regulation'. The latter contains a list of wastes in which all hazardous wastes have been marked *. For both this list and the rules for its application, please see the aforementioned regulations.
HBCDD	Hexabromocyclododedane, $C_{12}H_{18}Br_6$ (641.7 g/mol)  The primary use for HBCDD in the EU has been as flame retardant in expanded polystyrene (EPS) and extruded polystyrene (XPS) foam insulation between the late 1960's and 2015.
Household waste *	Waste originating from private households, except for collected components of such waste concerns that are designated as hazardous waste. *: Environmental Management Act
Household waste recycling centre (HWRC)	A Household Waste Recycling Centre (in Dutch "milieustraat", "milieupark" of "Afvalbrengstation") is a local or regional facility where inhabitants from a municipality or region can bring their (bulky) household waste and where his waste is collected separately in a large number of different waste streams. In the Netherlands EPS packaging waste is one of these separate waste streams.

Residual household waste	Mixture of waste produced by households after individual components (organic waste, paper/cardboard, glass, etc.) have been kept separate and collected/disposed of separately.
Collection *	Collection of waste, including preliminary sorting and preliminary storage of waste, and transport of such waste to a processing facility or application site. In waste collection, waste is collected and the collecting party assumes ownership of the waste from the eliminating party at the time of delivery. *: Environmental Management Act Note on the collection concept: Collection is an active professional operation where an agency or undertaking becomes the holder of waste that is presented by an eliminating party. • When an undertaking stores waste within its own facilities that was brought there by an eliminating party, such as in the context of old-for-new product schemes, that is deemed not collection but storage prior to collection. Subsequent retrieval of the collected waste from such facility by a professional collecting or processing agent is however considered collection. • Removing waste produced outside a party's own facility during professional activity (e.g. a gardener taking away pruning waste, a painter taking away used paint tins) is not considered commercial collection. When a professional waste collecting or processing agent collects the waste from the gardener or painter, that is considered commercial collection. • A vendor of household appliances removing an old washing machine from a private consumer's home when delivering a new machine. The collection on behalf of such vendor of the same washing machine from the same private consumer's home for storage in the latter's own facility is however considered commercial collection.
Minimum standard	The minimum quality of processing and handling of separate waste materials or waste categories. The minimum standard forms a reference for the maximum environmental impact which this processing or handling of (a category of) waste may cause. The standard is an implementation of the waste hierarchy for individual waste materials, and in this way forms a reference level in the granting of permits for waste management. This is also an elaboration of Articles 3 and 4 of the Waste Framework Directive.
Other recovery	Recovery other than 'preparation for reuse' or 'recycling'. Examples (without limitation, not necessarily in hierarchical order) are: - primary use as fuel - filling (*) - use as a reducing agent in blast furnaces (*) - etc. (*) provided that use of a primary material for such application is avoided Explanation: Essential for the distinction between 'recycling' and 'other recovery' is often the phrase in the definition of recycling: "...()... whereby waste types are reprocessed into products, materials or substances ... () ...". Because of this requirement, applications such as 'use as a reducing agent in blast furnaces', 'use as a flocculating agent', 'use as a DeNOx agent' and 'detonation' do not constitute recycling.
PolyFR	PolyFR is on the market since 2011 and is the broadly applied alternative for HBCDD in extruded polystyrene (XPS) and expanded polystyrene (EPS) foams after HBCDD being added to the Stockholm Convention in 2013. It is a butadiene styrene brominated copolymer; a stable high molecular weight additive, that is non-persistant, non-bioaccumulative and non-toxic (non-PBT). It is insoluble in acetone.

Recovery *	Any operation the principal result of which is waste serving an useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy; these operations include at least those described in Annex II to the Waste Framework Directive (2008/98/EC). *: Environmental Management Act
Recyclate	Substance or material produced from waste that can be used as a base material without further processing. This could still be a waste, or could already be end-of-waste if the relevant conditions are met.
Recycling *	Recovery where waste is reprocessed into products, materials or substances, either for the original purpose or for a different purpose, including reprocessing of organic waste but not including energy recovery and reprocessing into materials intended for use as a fuel or filler. *: Environmental Management Act
Sorting residue	Component stream resulting from the sorting of waste containing several material types, which remains after as many components as possible have been separated for recycling or recovery. Unlike a mixed fraction, a sorting residue is no longer reasonably suitable for further sorting/separation into materials that might then be separately made suitable for recycling. Residual household waste and mixed construction and demolition waste does not constitute a sorting residue (but rather a ‘mixed fraction’) in all cases where the material has not (yet) been processed in a mechanical sorting plant.
Sorting	Separating a mixture of material streams or of composite materials separate into their original material streams.
Municipal waste [general meaning]	Waste, not being aqueous waste, that is collected by and/or on behalf of municipalities; for the Netherlands this extends mainly to household waste and bulky household waste, but the definition also includes waste collected by or on behalf of municipalities from public areas, and waste from mostly small undertakings.
Incineration as a form of recovery	The incineration of waste with the main purpose of using the waste to produce energy. That means that the waste then fulfils an useful function because it is used instead of a primary energy source that would otherwise have been used for this purpose. This means that incineration of waste in a power plant, cement furnace etc. is considered recovery.
Disposal *	Any operation involving waste that is not recovery, even if the operation later causes substances or energy to be recovered. This includes at least the operations as referred to in Annex I to the Waste Framework Directive (2008/98/EC). *: Environmental Management Act
XPS	Extruded polystyrene (EPS) is foamed product made out of polystyrene through an extrusion process. Polystyrene is (PS) is a synthetic aromatic polymer made from the monomer styrene.

Annex 8 – Differences between planned and executed measurement programme

The planned measurement programme consisted of 1,518 measurements in Phase 1 (XRF screening), 69 measurements in Phase 2 (XRF measurements with extractive method) and 18 measurements in Phase 3 (LC-MS analysis) with a specific division of these measurements over e various types of EPS/XPS products and waste streams. The measurement programme that is executed differed slightly from the planned programme. In this annex this differences and the reasons for these differences are described.

Phase 1 – XRF screening

An overview of the planned and executed measurement programme of Phase 1 is presented in Table A8.1. In the last column remarks are made on the differences.

Table A8.1: Overview of planned and executed measurement programme Phase 1

life cycle phase	type of material	XRF screening no. of samples planned (-)	no. of locations planned(-)	XRF screening no. of samples actual (-)	no. of locations actual (-)	Remark
import	packaging	60	3	107	3	
	horticulture	20	2	0	0	not found
	ice box	20	2	18	1	only 1 location visited
	construction	20	2	8	4	only few samples found
	civil	4	2	0	0	not found
	transport sector	48	2	10	1	only 1 location found, little relevance
production	raw material (beads)	0	0	4	1	not foreseen
	packaging	12	3	22	3	
	specific product	0	0	13	2	
	horticulture	6	2	12	3	
	ice box	6	2	7	2	
	construction	12	3	40	6	
	civil	6	2	4	1	only 1 location found
	transport sector	12	3	0	0	not visited, little relevance
collection	packaging	400	4	493	5	
	horticulture	200	2	4	2	only few samples analyzed
	ice box	200	2	21	1	only few samples analyzed
	construction	200	2	283	4	
	civil	200	2	1	1	no more samples found
	transport sector	12	3	35	2	
recycling	recycling loose particles	40	2	44	2	
	recycling civil	20	1	0	0	no samples found
	recycling PS granulate	20	1	24	1	
disposal	incineration	n.a.		n.a.		
	landfill	n.a.		n.a.		
Total		**1518**	**47**	**1150**	**45**	

For most EPS/XPS products and wastes the number of samples that were analysed equal or surpass the number of planned measurements. Less measurements than planned were done in the categories “horticulture”, “ice box” and “civil”. During the measurement period “civil” samples were not found, notwithstanding the fact that an inquiry for these samples set out in the Rijkswaterstaat organization.

Less measurements than planned were done on “horticulture” and “ice box” samples. The main reason for this is that parties that collect these materials were not found. The conclusion is that most of these materials go directly from the producer of the waste to the recycler, without transhipment. Because practically all samples from “horticulture” and “ice box” did not contain bromine, it is unlikely that more samples would lead to a different outcome of the investigation.

Phase 2 – XRF measurement using extractive method

According to plan in Phase 2 a total of 69 samples from EPS/XPS products and wastes is analysed. Apart from this the samples of the standard samples of EPS beads of 100 and 1000 ppm HBCDD are analysed. In the right column remarks are made on the differences between the planned and executed measurement programme.

Table A8.2: Overview of planned and executed measurement programme Phase 2

type of material	life cycle phase	XRF measurement no. of samples planned (-)	XRF measurement no. of samples executed (-)	remarks
packaging	import	15	3	
horticulture	import	2	0	not found
ice box	import	2	0	all samples phase 1 with no/low bromine content
construction	import	8	6	
civil	import	2	0	not found
transport sector	import	8	0	no sample available
raw material (beads)	production	0	1	note foreseen during planning
packaging	production	2	5	
horticulture	production	2	0	no samples containing bromine
ice box	production	2	0	no samples containing bromine
construction	production	2	8	
civil	production	2	2	
transport sector	production	2	0	no sample available
packaging	collection	0	13	samples found containing bromine
horticulture	collection	2	1	only one sample containing bromine
ice box	collection	2	1	only one sample containing bromine
construction	collection	0	13	a number of different samples selected
civil	collection	0	2	samples available
transport sector	collection	8	3	only three relevant samples
recycling loose particles	recycling	4	8	a number of different samples selected
recycling civil	recycling	2	0	no sample available
recycling PS granulate	recycling	2	3	
Total		**69**	**69**	

Phase 3 – LC-MS analysis

In Phase 3 a total of 26 samples from EPS/XPS products and wastes is analysed. Apart from this the samples of the standard samples of EPS beads of 100 and 1000 ppm HBCDD are analysed.

The selection process for Phase 3 was simple. All the samples that showed the occurrence of a soluble brominated component in the sample in Phase 2 were selected for Phase 3. The only exception was one sample from "collection – construction". For this sample not enough material was left for the Phase 3 analysis. An overview of the planned and executed measurement programme of Phase 3 is presented in Table A8.3.

Table A8.3: Overview of planned and executed measurement programme Phase 3

type of material	life cycle phase	GC-MS no. of samples planned (-)	GC-MS no. of samples executed (-)
packaging	import	4	1
horticulture	import		
ice box	import		
construction	import	2	
civil	import		
transport sector	import	2	
packaging	production		
horticulture	production		
ice box	production		
construction	production		1
civil	production		2
transport sector	production		
packaging	collection		9
horticulture	collection		1
ice box	collection		1
construction	collection		5
civil	collection		
transport sector	collection	2	3
recycling loose particles	recycling	4	4
recycling civil	recycling	2	
recycling PS granulate	recycling	2	1
incineration	disposal		
landfill	disposal		
Total		**18**	**28**

Annex 9 – Test report analysis with LC-MS

Test Report
Prüfbericht

Customer: *Kunde:*	**Giraf Results**		
	Koningsweg 173 3585 LC Utrecht Niederlande	**Report No.:** *Berichtsnr.:*	(25418)061-385829
		Report Version: *Berichtsversion:*	1
Contact Person: *Ansprechpartner:*	Mrs. Alix Reichenecker	**Date of Reception:** *Probeneingang:*	05.02.2018
		Report Date: *Berichtsdatum:*	02.03.2018
		Date of Order: *Auftragsdatum:*	02.02.2018
		Sampled By: *Probennehmer:*	client

Sample Information
Probeninformation

Testing Requirements: *Anforderungen:*	Tested according to "ordered/ beauftragten" requirements *Geprüft nach "ordered/ beauftragten" Anforderungen*
Sample Description: *Probenbeschreibung:*	Polstyrene samples *Styropor Muster*

Performance Date: *Bearbeitungszeitraum:*	26.02.2018 - 02.03.2018 *26.02.2018 - 02.03.2018*	**No. of workdays:** *Arbeitstage:*	4 *4*

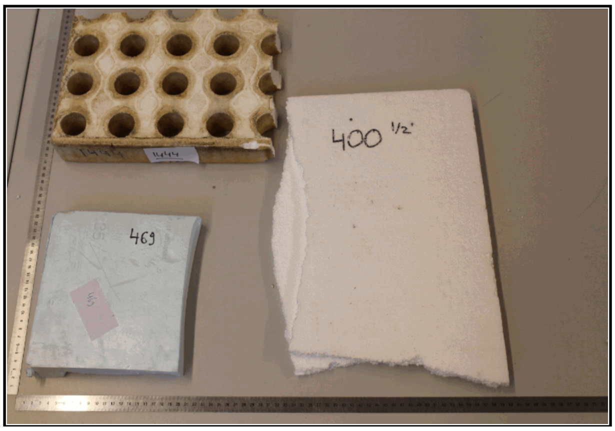
Submitted Samples

Gelieferte Muster

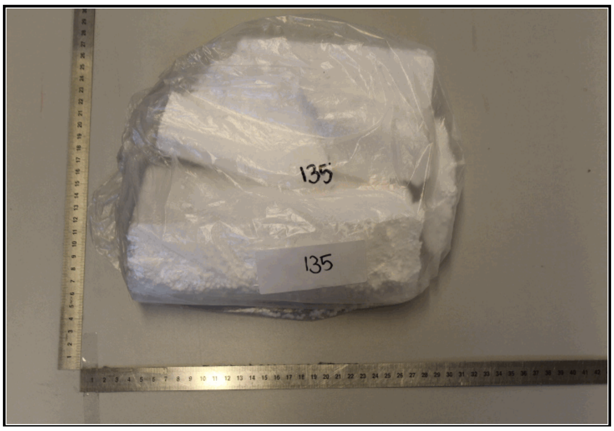
Nr. 1

Nr. 2

Nr. 3



Nr. 4



Summary of Test Results

Zusammenfassung der Prüfergebnisse

Tested according to "ordered/ beauftragten" requirements

Geprüft nach "ordered/ beauftragten" Anforderungen

Tests required *Beauftragte Prüfungen*	**Conclusion** *Bewertung*	**Remark** *Bemerkung*
HBCDD [Hexabromocyclododecane] *HBCDD [Hexabromcyclododecane]*	No Conclusion Keine Bewertung	

Please note:
The results were taken from the project 383191_V2 and project 383872.

Bitte beachten:
Die Ergebnisse wurden von Projekt 383191_V2 und Projekt 383872 übernommen.

Tested Samples
Prüflinge

Article No *Artikel-Nr.*	**Sample ID** *Probennummer*	**Sample description**	*Beschreibung des Prüflings*
	385829-01	1) Polystyrene foam green (1232)	*1) Styropor grün (1232)*
	385829-02	2) Polystyrene foam white/brown (E1, 827, SZZ)	*2) Styropor weiß/braun (E1, 827, SZZ)*
	385829-03	3) Foam mixture dark brown	*3) Schaumstoff Mix dunkelbraun*
	385829-04	4) Foam mixture dark brown	*4) Schaumstoff Mix dunkelbraun*
	385829-05	5) Polystyrene balls white/grey (771)	*5) Styroporkügelchen weiß/grau (771)*
	385829-06	6) Polystyrene balls white/grey (769)	*6) Styroporkügelchen weiß/grau (769)*
	385829-07	7) Plastic balls white (10.002; 1000ppm HBCD)	*7) Kunststoffkügelchen weiß (10.002; 1000ppm HBCD)*
	385829-08	8) Plastic balls white (10.001; 100ppm HBCD)	*8) Kunststoffkügelchen weiß (10.001; 100ppm HBCD)*
	385829-09	9) Polystyrene balls white (760)	*9) Styroporkügelchen weiß (760)*
	385829-10	10) Polystyrene foam white (468)	*10) Styroporweiß (468)*
	385829-11	11) Polystyrene foam white (1024)	*11) Styropor weiß (1024)*
	385829-12	12) Polystyrene foam white/sand (1444)	*12) Styropor weiß/sand (1444)*
	385829-13	13) Polystyrene foam light blue (469)	*13) Styropor hellblau (469)*
	385829-14	14) Polystyrene foam white (400 1/2)	*14) Styropor weiß (400 1/2)*
	385829-15	15) Polystyrene foam white (400 2/2)	*15) Styropor weiß (400 2/2)*
	385829-16	16) Polystyrene foam white	*16) Styropor weiß*
	385829-17	17) Polystyrene foam white/dark grey (1110)	*17) Styropor weiß/dunkelgrau (1110)*
	385829-18	18) Polystyrene foam white (261 1/3)	*18) Styropor weiß (261 1/3)*
	385829-19	19) Polystyrene foam white (261 2/3)	*19) Styropor weiß (261 2/3)*
	385829-20	20) Polystyrene foam white (261 3/3)	*20) Styropor weiß (261 3/3)*
	385829-21	21) Polystyrene foam white/dark grey (1114)	*21) Styropor weiß/dunkelgrau (1114)*
	385829-22	22) Plastic granulate honey (797)	*22) Kunststoffgranulat honig (797)*
	385829-23	23) Polystyrene foam white (890)	*23) Styropor weiß (890)*
	385829-24	24) Polystyrene foam white (230)	*24) Styropor weiß (230)*
	385829-25	25) Polystyrene foam white (615)	*25) Styropor weiß (615)*
	385829-26	26) Polystyrene foam offwhite (861)	*26) Styropor ecru (861)*
	385829-27	27) Polystyrene foam white (520 1/2)	*27) Styropor weiß (520 1/2)*
	385829-28	28) Polystyrene foam white (520 2/2)	*28) Styropor weiß (520 2/2)*
	385829-29	29) Polystyrene foam white (408)	*29) Styropor weiß (408)*
	385829-30	30) Polystyrene foam white (522)	*30) Styropor weiß (522)*
	385829-31	31) Polystyrene foam white (135)	*31) Styropor weiß (135)*

Test Results
Prüfergebnisse

Tested according to "ordered/ beauftragten" requirements
Geprüft nach "ordered/ beauftragten" Anforderungen

Sample Description:	1) Polystyrene foam green (1232)	Lab Reference No:	385829-01
Probenbeschreibung:	*1) Styropor grün (1232)*	***Labor-Referenz-Nr.:***	*385829-01*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		12400 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		2700 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		2000 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	2) Polystyrene foam white/brown (E1, 827, SZZ)	Lab Reference No:	385829-02
Probenbeschreibung:	*2) Styropor weiß/braun (E1, 827, SZZ)*	***Labor-Referenz-Nr.:***	*385829-02*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		19 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		16 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		180 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	3) Foam mixture dark brown	Lab Reference No:	385829-03
Probenbeschreibung:	*3) Schaumstoff Mix dunkelbraun*	***Labor-Referenz-Nr.:***	*385829-03*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	4) Foam mixture dark brown	Lab Reference No:	385829-04
Probenbeschreibung:	*4) Schaumstoff Mix dunkelbraun*	***Labor-Referenz-Nr.:***	*385829-04*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	5) Polystyrene balls white/grey (771)	Lab Reference No:	385829-05
Probenbeschreibung:	*5) Styroporkügelchen weiß/grau (771)*	***Labor-Referenz-Nr.:***	*385829-05*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		50 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		40 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		450 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	6) Polystyrene balls white/grey (769)	Lab Reference No:	385829-06
Probenbeschreibung:	*6) Styroporkügelchen weiß/grau (769)*	***Labor-Referenz-Nr.:***	*385829-06*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		56 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		50 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		420 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	7) Plastic balls white (10.002; 1000ppm HBCD)	Lab Reference No:	385829-07
Probenbeschreibung:	*7) Kunststoffkügelchen weiß (10.002; 1000ppm HBCD)*	***Labor-Referenz-Nr.:***	*385829-07*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		150 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		85 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		550 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	8) Plastic balls white (10.001; 100ppm HBCD)	Lab Reference No:	385829-08
Probenbeschreibung:	*8) Kunststoffkügelchen weiß (10.001; 100ppm HBCD)*	***Labor-Referenz-Nr.:***	*385829-08*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		15 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		57 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	9) Polystyrene balls white (760)	Lab Reference No:	385829-09
Probenbeschreibung:	*9) Styroporkügelchen weiß (760)*	***Labor-Referenz-Nr.:***	*385829-09*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		56 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	10) Polystyrene foam white (468)	**Lab Reference No:**	385829-10
Probenbeschreibung:	*10) Styroporweiß (468)*	***Labor-Referenz-Nr.:***	*385829-10*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	**Limit / Grenzwert**	**Result / Ergebnis**	**Rating / Bewertung**
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		27 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	11) Polystyrene foam white (1024)	**Lab Reference No:**	385829-11
Probenbeschreibung:	*11) Styropor weiß (1024)*	***Labor-Referenz-Nr.:***	*385829-11*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	**Limit / Grenzwert**	**Result / Ergebnis**	**Rating / Bewertung**
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		580 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		710 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		4010 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	12) Polystyrene foam white/sand (1444)	**Lab Reference No:**	385829-12
Probenbeschreibung:	*12) Styropor weiß/sand (1444)*	***Labor-Referenz-Nr.:***	*385829-12*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	**Limit / Grenzwert**	**Result / Ergebnis**	**Rating / Bewertung**
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		18 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		210 mg/kg	No Specification *Keine Spezifikation*

Sample Description: ***Probenbeschreibung:***	13) Polystyrene foam light blue (469) *13) Styropor hellblau (469)*	**Lab Reference No:** ***Labor-Referenz-Nr.:***	385829-13 *385829-13*

Test Method / Standard:	Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg
Prüfmethode / Norm:	*Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*
Test Location: ***Prüfstandort:***	Parameter has been analyzed at BVCPS laboratory Schwerin. *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		13500 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		2500 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		2100 mg/kg	No Specification *Keine Spezifikation*

Sample Description: ***Probenbeschreibung:***	14) Polystyrene foam white (400 1/2) *14) Styropor weiß (400 1/2)*	**Lab Reference No:** ***Labor-Referenz-Nr.:***	385829-14 *385829-14*

Test Method / Standard:	Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg
Prüfmethode / Norm:	*Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*
Test Location: ***Prüfstandort:***	Parameter has been analyzed at BVCPS laboratory Schwerin. *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		700 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		430 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		3900 mg/kg	No Specification *Keine Spezifikation*

Sample Description: ***Probenbeschreibung:***	15) Polystyrene foam white (400 2/2) *15) Styropor weiß (400 2/2)*	**Lab Reference No:** ***Labor-Referenz-Nr.:***	385829-15 *385829-15*

Test Method / Standard:	Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg
Prüfmethode / Norm:	*Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*
Test Location: ***Prüfstandort:***	Parameter has been analyzed at BVCPS laboratory Schwerin. *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		640 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		410 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		3700 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	16) Polystyrene foam white	Lab Reference No:	385829-16
Probenbeschreibung:	*16) Styropor weiß*	***Labor-Referenz-Nr.:***	*385829-16*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	17) Polystyrene foam white/dark grey (1110)	Lab Reference No:	385829-17
Probenbeschreibung:	*17) Styropor weiß/dunkelgrau (1110)*	***Labor-Referenz-Nr.:***	*385829-17*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	18) Polystyrene foam white (261 1/3)	Lab Reference No:	385829-18
Probenbeschreibung:	*18) Styropor weiß (261 1/3)*	***Labor-Referenz-Nr.:***	*385829-18*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		660 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		420 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		4200 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	19) Polystyrene foam white (261 2/3)	Lab Reference No:	385829-19
Probenbeschreibung:	*19) Styropor weiß (261 2/3)*	***Labor-Referenz-Nr.:***	*385829-19*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		24 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		14 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		160 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	20) Polystyrene foam white (261 3/3)	Lab Reference No:	385829-20
Probenbeschreibung:	*20) Styropor weiß (261 3/3)*	***Labor-Referenz-Nr.:***	*385829-20*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		780 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		450 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		5040 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	21) Polystyrene foam white/dark grey (1114)	Lab Reference No:	385829-21
Probenbeschreibung:	*21) Styropor weiß/dunkelgrau (1114)*	***Labor-Referenz-Nr.:***	*385829-21*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		33 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	22) Plastic granulate honey (797)	Lab Reference No:	385829-22
Probenbeschreibung:	*22) Kunststoffgranulat honig (797)*	***Labor-Referenz-Nr.:***	*385829-22*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	23) Polystyrene foam white (890)	Lab Reference No:	385829-23
Probenbeschreibung:	*23) Styropor weiß (890)*	***Labor-Referenz-Nr.:***	*385829-23*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		36 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		26 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		160 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	24) Polystyrene foam white (230)	Lab Reference No:	385829-24
Probenbeschreibung:	*24) Styropor weiß (230)*	***Labor-Referenz-Nr.:***	*385829-24*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		26 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		14 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		230 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	25) Polystyrene foam white (615)	Lab Reference No:	385829-25
Probenbeschreibung:	*25) Styropor weiß (615)*	***Labor-Referenz-Nr.:***	*385829-25*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		14 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		39 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		130 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	26) Polystyrene foam offwhite (861)	Lab Reference No:	385829-26
Probenbeschreibung:	*26) Styropor ecru (861)*	***Labor-Referenz-Nr.:***	*385829-26*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		170 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		78 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		6200 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	27) Polystyrene foam white (520 1/2)	Lab Reference No:	385829-27
Probenbeschreibung:	*27) Styropor weiß (520 1/2)*	***Labor-Referenz-Nr.:***	*385829-27*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	28) Polystyrene foam white (520 2/2)	Lab Reference No:	385829-28
Probenbeschreibung:	*28) Styropor weiß (520 2/2)*	***Labor-Referenz-Nr.:***	*385829-28*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	29) Polystyrene foam white (408)	Lab Reference No:	385829-29
Probenbeschreibung:	*29) Styropor weiß (408)*	***Labor-Referenz-Nr.:***	*385829-29*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		650 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		430 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		3300 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	30) Polystyrene foam white (522)	Lab Reference No:	385829-30
Probenbeschreibung:	*30) Styropor weiß (522)*	***Labor-Referenz-Nr.:***	*385829-30*

Test Method / Standard: Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg

Prüfmethode / Norm: *Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*

Test Location: Parameter has been analyzed at BVCPS laboratory Schwerin.

Prüfstandort: *Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		480 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		400 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		3400 mg/kg	No Specification *Keine Spezifikation*

Sample Description:	31) Polystyrene foam white (135)	**Lab Reference No:**	385829-31
Probenbeschreibung:	*31) Styropor weiß (135)*	***Labor-Referenz-Nr.:***	*385829-31*

Test Method / Standard:	Hexabromocyclododecane (HBCDD): BVCPS inhouse method, extraction with Methanol, analysis by LC-MS, reporting limit: 10 mg/kg
Prüfmethode / Norm:	*Hexabromcyclododecane (HBCDD): BVCPS Inhouse Methode, Extraktion mit Methanol, Analyse mittels LC-MS, Berichtsgrenze: 10 mg/kg*
Test Location:	Parameter has been analyzed at BVCPS laboratory Schwerin.
Prüfstandort:	*Parameter wurde im BVCPS Labor Schwerin geprüft.*

Parameter	Limit / Grenzwert	Result / Ergebnis	Rating / Bewertung
Alpha-Hexabromocyclododecane (Alpha-HBCDD) Alpha-Hexabromcyclododecan (Alpha-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Beta-Hexabromocyclododecane (Beta-HBCDD) Beta-Hexabromcyclododecan (Beta-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*
Gamma-Hexabromocyclododecane (Gamma-HBCDD) Gamma-Hexabromcyclododecan (Gamma-HBCDD)		<10 mg/kg	No Specification *Keine Spezifikation*

The testing of mixed samples is carried out at the customer's explicit request and may imply a deviation from the testing standard. Please note the following: results for mixed samples that are below the limit may exceed the limit if the samples contained in the mixed sample are tested individually. In these cases separate testing of the samples is recommended.

Die Untersuchung von Mischproben erfolgt auf Wunsch des Kunden und beinhaltet gegebenenfalls eine Abweichung von der Norm. Bitte beachten Sie dabei folgendes: Ergebnisse, die bei Mischproben noch unterhalb des Grenzwertes liegen, können, bei separater Prüfung der in der Mischprobe enthaltenen Einzelproben, über dem Grenzwert liegen. In diesem Fall wird empfohlen, Einzelprüfungen durchzuführen.

Performance Date:	26.02.2018 - 02.03.2018
Bearbeitungszeitraum:	
Total Run Time:	4
Analysendauer:	*4*

Ute Freymann

Ute Freymann
Analytical Testing Specialist

No results printed beyond this point in the report

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Parameters & CAS No.
Parameter & CAS Nr.

Hexabromocyclododecane (HBCDD) ***Hexabromcyclododecane (HBCDD)***	**(CAS No.)** ***(CAS Nr.)***
Alpha-Hexabromocyclododecane (Alpha-HBCDD) (134237-50-6) *Alpha-Hexabromcyclododecan (Alpha-HBCDD) (134237-50-6)*	
Beta-Hexabromocyclododecane (Beta-HBCDD) (134237-51-7) *Beta-Hexabromcyclododecan (Beta-HBCDD) (134237-51-7)*	
Gamma-Hexabromocyclododecane (Gamma-HBCDD) (134237-52-8) *Gamma-Hexabromcyclododecan (Gamma-HBCDD) (134237-52-8)*	

8 DOCUMENT DATA

Client	:	Ministry of Infrastructure and Water Management
Project	:	HBCDD concentrations in EPS/XPS products and waste streams in the Netherlands
File	:	P123.01
Report size	:	59 pages
Authors	:	J. van Dijk M.Sc., A. Reichenecker M.Sc.
Date	:	15 March 2018

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